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Storage for Storm Water Quality Control - Meadowvale Test Site Study

Research Report No. 63

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1977
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earch Program for the Abatement of Municipal Pollution
under Provisions of the Canada-Ontario Agreement
on Great Lakes Water Quality

Research Report No. 63 Meadowvale Test Site Study

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STORAGE FOR STORM WATER QUALITY CONTROL - MEADOWVALE TEST SITE STUDY

by

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RESEARCH PROGRAM FOR THE ABATEMENT
OF MUNICIPAL POLLUTION WITHIN THE
PROVISIONS OF THE CANADA-ONTARIO
AGREEMENT ON GREAT LAKES WATER QUALITY

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ABSTRACT

Two computer models, the U.S. Environmental Protection Agency's SWMM and the U.S. Army Corps of Engineers' STORM, were applied for simulation of urban runoff phenomena in a test catchment of the "new town" of Meadowvale prior to development and after its completion. A special subroutine for the STORM model was developed to simulate the performance of an in-stream settling basin-reservoir system for storm water quality control.

It was predicted that the uncontrolled urbanization of the Meadowvale catchment would lead to a deterioration of storm water quality. Expected increases in annual pollutant yields (compared with undeveloped conditions) would be: BOD from 4 to 26 lb/acre; SS from 34 to 171 lb/acre; nitrogen from 1 to 10 lb/acre, and, orthophosphate from 0.4 to 1 lb/acre. Hydrologically, peak flows might increase by a factor ranging from two to five depending on the storm frequency, while the total annual runoff would increase from 4.1 inches/annum to 8 inches/annum. The settling basin-reservoir system to be constructed at Meadowvale should significantly improve runoff characteristics. Predicted yields of pollutants passing through the system to the Credit River were: BOD - 1.1 lb/acre; SS - 11 lb/acre; nitrogen - 7 lb/acre; and orthophosphate - 0.8 lb/acre. Peak flow rates would drop, the actual reduction in the flow rate depending on the size and temporal pattern of the storm. It was estimated that the system designed for Meadowvale would reduce peak flows to pre-urbanized levels or less for storms with return periods less than one year. The studied system of storm water quality control appears to be very attractive. However, future measurements are required to calibrate the applied models and verify the accepted assumptions.

RÉSUMÉ

Les auteurs se sont servi de deux modèles informatiques, le SWMM* de l'EPA des É.-U. et le STORM du U.S. Army Corps of Engineers, pour simuler le ruissellement dans un bassin donné d'une ville modèle, Meadowvale, avant et après l'aménagement. Ils sont mis au point, pour le modèle STORM, un sous-programme qui simule l'épuration des eaux pluviales dans un bassin de stabilisation.

Il ressort de ces simulations que l'urbanisation "sauvage" de Meadowvale entraînerait une forte diminution de la qualité des eaux pluviales. Au bout d'un an, la pollution résultante se traduirait par une augmentation de la DBO de 4 à 26 lb/acre, des matières en suspension (MES) de 43 à 171 lb/acre, de l'azote de 1 à 10 lb/acre, et des orthophosphates de 0,4 à 1 lb/acre. Du point de vue hydrologique, le débit maximal pourrait doubler et même quintupler, selon la fréquence des pluies, tandis que la quantité d'eau de ruissellement annuelle passerait de 4,1 à 8 pouces. L'aménagement du bassin de stabilisation devrait améliorer sensiblement la situation. Après avoir traversé le système, les quantités prévues de pollutants rejetés dans la rivière Credit seraient les suivantes: 1,1 lb/acre pour la DBO, 11 lb/acre pour les MES, 7 lb/acre pour l'azote, et 0,8 lb/acre pour les orthophosphates. Les débits maximaux, variables suivant l'importance et la durée des pluies, baisseraient aussi. Dans le cas de pluies dont le cycle est de moins d'un an, on estime que le système conçu pour Meadowvale ramènerait les débits maximaux à des valeurs égales ou inférieures à celles d'avant l'urbanisation. Le système d'épuration des eaux pluviales étudié semble avantageux. Il serait toutefois nécessaire de prendre d'autres mesures pour étalonner les modèles et vérifier les hypothèses formulées.

* SWMM (Storm Water Management Model)

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CONCLUSIONS

The following conclusions can be drawn from the performed simulations of the Meadowvale test catchment:

1) Urbanization of the Meadowvale catchment will lead to a deterioration of storm water quality. Expected increases in annual pollutant yields as compared with the undeveloped conditions are: BOD from 4 to 26 lb/acre; SS from 34 to 171 lb/acre; nitrogen from 1 to 10 lb/acre; and orthophosphate from 0.4 to 1 lb/acre. Hydrologically, peak flows may increase by a factor ranging from two to five depending on the storm frequency, while the total annual runoff would increase from 4.1 in/annum to 8 in/annum.

2) The silting basin with the dam to be constructed at Meadowvale should significantly improve runoff characteristics. Predicted yields of pollutants passing through the system to the Credit River are: BOD - 1.1 lb/acre; SS - 11 lb/acre; nitrogen - 7 lb/acre; and orthophosphate - 0.8 lb/acre. Peak flow rate drops, the actual reduction in the flow rate depending on the size and temporal pattern of the storm. It is estimated that the system as designed at Meadowvale will reduce peak flows to pre-urbanized levels or less for storms with return periods less than one year.

3) For the design of storage systems in residential developments such as Meadowvale, consideration should be given to the use of two spillways, one to restrict flow and allow the use of available storage, and the second to cater to large events (i.e., greater than some nominal return period, say 25 years). The increased costs of a higher dam and higher flood servitudes around the dam should not be significant at this scale of project, whereas the benefits of peak flow reduction are considerable. It may be possible to control storm water flow by designing the system for peak flow reduction, the assumption being that if peak flows are reduced to pre-urban values, problems of erosion, flooding and pollution will be checked at acceptable levels.

4) Based on predictions of pollutant concentrations in the reservoir, a seasonal algae growth can be expected. This problem should be controlled.

5) The expected buildup of sludge will be slow, chiefly due to the large area available for sludge storage, averaging 0.05 in/annum. Even during construction of the remaining undeveloped land, build-up of sludge will only be moderate. The basin will trap flotables and has the potential to become anaerobic. A program for regular drawdown and cleaning should, therefore, be planned.

RECOMMENDATIONS

1) The storm water quality control system composed of a settling tank followed by a water reservoir, may be recommended as a relatively simple and reliable method for storm water pollution abatement in new residential developments.

2) Future monitoring of the Meadowvale test site is required to calibrate the models applied in this study and verify the accepted assumptions. Most sensitive parameters are: imperviousness, catchment width, infiltration capacity, surface depression, roughness and slope (listed in order of decreasing importance).

3) Many aspects of the suggested storm water control method are still not known well enough and require further research. More specifically:

   (a) The settling behaviour of the storm water solids should be studied with particular emphasis on the removals of nutrients and heavy metals obtainable under different hydraulic loadings.

   (b) The reservoir quality simulation algorithms should be tested. It is probable that a more sophisticated approach (eg. a biological model of the nutrient balance) may be necessary if acceptable results are to be obtained.

   (c) The significance of snowmelt on the reservoir water quality should be studied.

   (d) The microbiological quality of the storm water runoff and the effects of prolonged storage on bacterial populations should be examined.

1. INTRODUCTION

In the past five years there has been a proliferation of computer models for the simulation of the urban runoff phenomena. This study has been based on two such models: SWMM, developed for the U.S. Environmental Protection Agency by Metcalf and Eddy, Inc., the University of Florida, and Water Resources Engineers, Inc.; and STORM, developed by Water Resources Engineers and currently managed by the U.S. Army Corps of Engineers. Both of these models have been used without any initial calibration. Therefore, the results presented here have only preliminary character and must be verified by future measurements.

In this report, after presentation of general comments on the applied models (Chapter 3), the development of the new subroutine is described (Chapter 4). This is followed by the characterization of the test site (Chapter 5) and the results of the hydrological (Chapter 6) and pollution (Chapter 7) simulations. The new subroutine program "MIKE" is given in the appendix to this report.

2. OBJECTIVES

The objective of the study reported here was to examine the behaviour of the settling basin-reservoir system used to control quantity and quality of storm water from residential areas. For this purpose, the computer models and proper data for the test site were used to generate prediction of flow hydrographs, pollutographs and annual pollutant yields.

The proposed system at Meadowvale incorporates a siltation basin (40,000 ft^2/3700 m^2) followed by a larger reservoir (10 acres/4 hectares). A more detailed description of the catchment is given in Chapter 5. The catchment was simulated for before and after development conditions. Particular attention was paid to predicting pollutant yields, the quality of the reservoir water and the operational efficiency of the siltation basin.

Wherever possible, data from Meadowvale were used. Unfortunately quality simulations were based on assumed pollutant loading rates. The Ontario Ministry of the Environment will be monitoring, over the next four to five years, the performance of the Meadowvale system and will provide data to check this work.

3. RUNOFF MODELS

3.1 General

Runoff water quality predictions according to both the applied models (SWMM and STORM) are relatively inaccurate. This is due mostly to the preliminarily simplistic approach adopted for the logic in these models.

Some discussion of this approach seems essential.

3.2 SWMM

The Environmental Protection Agency's Storm Water Management Model (SWMM) is probably the most comprehensive urban runoff model currently available. It is well documented (Environmental Protection Agency, 1971) and is being applied by an increasing number of consultants and public authorities. For runoff and flow computations the model uses deterministic routines and is known to give acceptable results providing no surcharging occurs (MacLaren, 1975). Calibration of sensitive parameters is desirable but not essential.

Quality computations in this model are not as accurate. This is partly due to the simplistic approach adopted for modelling runoff quality, although the phenomenon itself is complex, stochastic and difficult to conceptualise. The salient features of the quality routine in SWMM are:

1) Dust and dirt build up on the subcatchments at a constant daily rate which is dependent on gutter length and land use. This rate of build up is the most sensitive parameter for quality simulation and, in general, the total amount of pollutant washed-off during a storm is approximately linearly proportional to the number of dry days previous to the storm.

2) Proportionality coefficients and specific pollutant loadings of dust and dirt are related to land use and built in as default values, making calibration a tedious procedure.

3) The rate of pollutant washoff explicitly depends on the runoff and implicitly on the rainfall intensity, as well

as on the availability of the pollutant. It is assumed that 90% of the available pollutant is washed off the catchment by a one-hour storm with an intensity of $\frac{1}{2}$ inch per hour (1.27 cm/hr). No pollutants are generated during runoff.

A recent paper by Colston and Tafuri (1975) reported the results of a study in Durham, North Carolina. Using water quality data from the runoff of 66 storms, statistical techniques were used to derive regression equations for pollutant concentrations and identify important variables. Four variables were investigated: the discharge rate, the time from storm start, the time from the previous storm, and the time from the last peak. They found that the discharge rate and the time from the storm start were significant while the other two variables yielded only a small gain in the correlation coefficient and could be ignored. A similar finding was also reported in a previous study made in Tulsa, Oklahoma (Environmental Protection Agency, 1970).

Thus, it appears that the SWMM procedure, in which the time from the last storm or the number of dry days is a controlling variable, may not be precise enough. Possibly the rate of turnover of pollutants on a catchment is a much slower process than assumed by SWMM, i.e., a storm would only remove a fraction of the pollutants on the catchment (possibly the available fraction) but because of erosive, wetting and drying processes the available fraction is generated soon after the end of the storm. In addition, SWMM does not recognize that for a nonconservative pollutant such as BOD, a steady state may exist where the rate of generation (from dust and dirt) equals the rate of decay. Conversely, coliform numbers may in fact increase given suitable environmental conditions. It appears that much research is needed to clarify how pollutants are deposited, washed-off and transported before a deterministic model can be developed.

Many researchers believe that there is no definable relationship for determining the quality of storm water from a specific event and that investigations should be directed at predicting aggregate (statistical) effects.

3.3 STORM

STORM is the planning model of the U.S. Army Corps of Engineers (1974). It permits the comparative analysis of different storm-treatment combinations for control of overflows. The program uses a storage-treatment hierarchy which is shown in Figure 1. This type of priority routing is ideally suited to the management of combined sewer overflows; however, for separate sewers (the typical arrangement in new residential developments), in-stream storage (Figure 1) is more practical. Some computational facility to simulate an in-stream reservoir is desirable for STORM; such a routine was developed and is discussed later in this report.

The program is designed for use of many years of continuous hourly precipitation records, but selected events may also be studied. For runoff computations, the program uses the following equation:

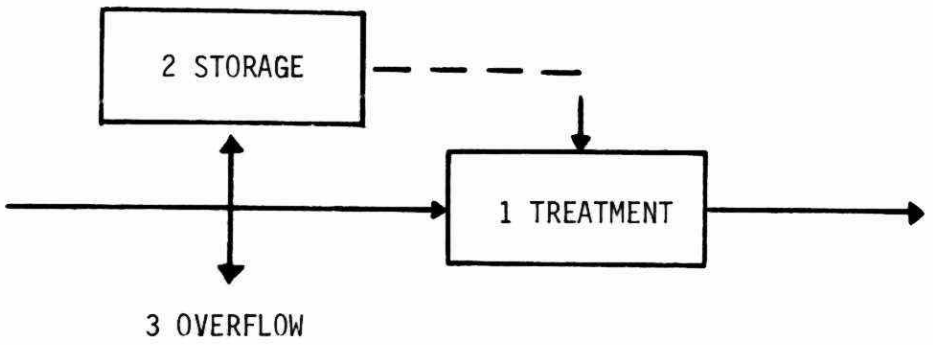
$$R = C(P - K) \cdot A$$

where: R = runoff (cfs),
C = runoff coefficient, a constant for the catchment,
P = precipitation in the hour (in),
K = depression storage at the beginning of the hour (in),
A = area (acres).

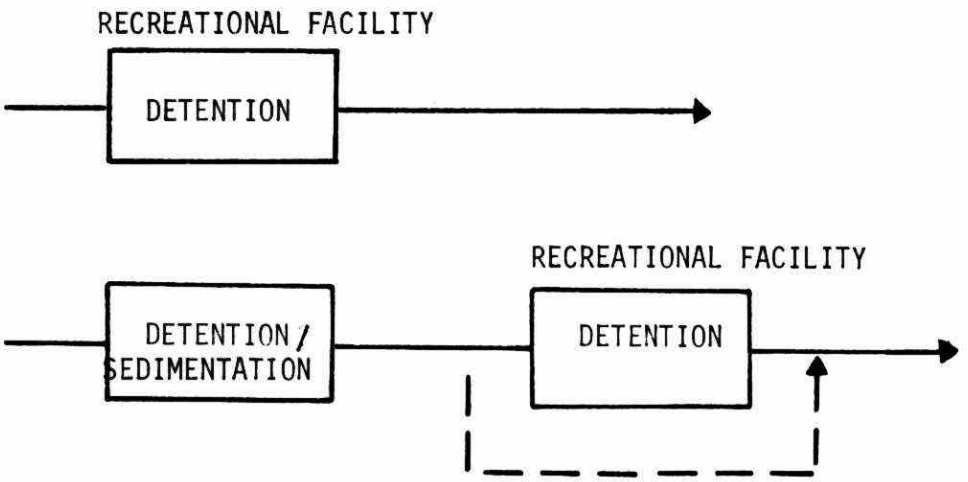
Although this appears at first sight to be the "rational formula", the precipitation is not based on an intensity-duration frequency curve. Depression storage is recovered between storms to a maximum user-specified depth. The major criticism of the runoff algorithm is the use of a constant runoff coefficient; in practice, the coefficient decreases as rainfall accumulates. The quality routine is analagous to that in SWMM already discussed; however, two points must be noted:

1) For SWMM, the initial load of pollutants in the catchment is determined by the number of dry days - a user specified parameter - but for STORM, buildup is a continuous process and in times of no rain may become excessive. The error is fortunately damped out. An upper limit for pollution buildup is required to solve the problem.

2) For STORM, the rate of pollutant buildup is an input option - a distinct advantage over the SWMM model.



PRIORITY ROUTING OF 'STORM'
USES DRY STORAGE BASIN,SUITABLE
FOR HANDLING COMBINED SEWER OVERFLOWS



TYPICAL MULTIPURPOSE SYSTEMS OF
DETENTION FOR STORMWATER MANAGEMENT
IN RESIDENTIAL AREAS

FIGURE 1. TYPICAL STORAGE SYSTEMS

4. SUBROUTINE "MIKE"

4.1 Development of the Subroutine

This subroutine, developed by M.P.H. Murrey, at the University of Toronto as part of this research, is an addition to STORM which permits the simulation of an in-stream settling basin-reservoir system. The two components are considered independently. A flow chart to illustrate the model logic is shown in Figure 2 and a listing of the program source and the necessary modifications to STORM are given in the appendix.

Input data for the subroutine is read in after the "T Group" cards described in the STORM User's Manual (1974). Input requirements and format are summarized in Table 1. The following sequence of computation is made for every hour of the simulation:

1) If runoff occurs and in-stream modelling is required, the routine is called; if not, computation proceeds in Main.

2) The number of hours since the previous runoff is calculated. The reservoir water quality and storage condition is updated for each hour using the following relations:

$$SS_1 = .88\ SS_0 \tag{1}$$

$$SETL\ S_1 = .88\ SETL\ S_0 \tag{2}$$

$$BOD_1 = BOD_0 \cdot 10^{-K_1 \cdot T} \tag{3}$$

$$OXDEF_1 = \frac{K_1}{K_2 - K_1} \times BOD_0 (10^{-K_1 \cdot T} - 10^{-K_2 \cdot T}) + OXDEF_0 \cdot 10^{-K_2 \cdot T} \tag{4}$$

$$DO_1 = DO_{SAT} - OXDEF_1 \tag{5}$$

$$(PO_4)_1 = (PO_4)_0 \tag{6}$$

$$N_1 = N_0 \tag{7}$$

$$STORAGE_1 = STORAGE_0 - EVAP \times AREA \tag{8}$$

where: T = time,

K_1 = deoxygenation coefficient = $0.15 \times 1.0471^{(\theta-20)}$,

K_2 = reaeration coefficient = $0.075 \times 1.0241^{(\theta-20)}$,

θ = temperature, ^{o}C,

DO_{SAT} = saturated dissolved oxygen concentration.

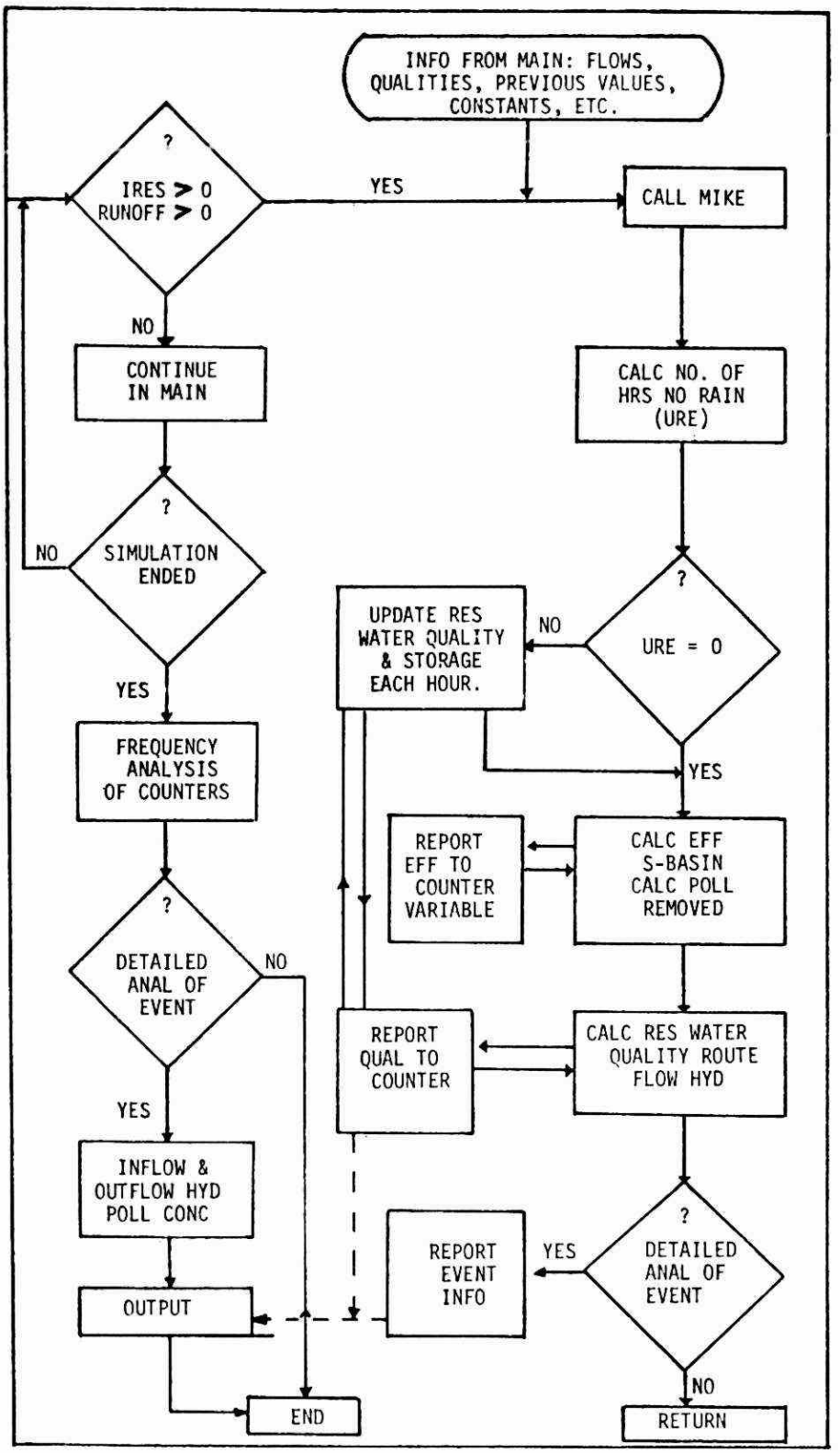


FIGURE 2. FLOW CHART FOR SUBROUTINE MIKE

TABLE 1. INPUT REQUIREMENTS AND FORMAT FOR SUBROUTINE MIKE

CARD	FORMAT	VARIABLE	DESCRIPTION
1	I5	IRES	IRES = 0 NO IN-STREAM RESERVOIR > 0 IN-STREAM RESERVOIR SIMULATED
2	(3F10.1, 2I5, F6.1)	PVOL	VOLUME OF SILTATION POND (ft^3)
		ARP1	AREA OF SILTATION POND (ft^2)
		RVOL	VOLUME OF RESERVOIR FULL (ft^3)
		WTP2	TYPE OF WEIR: < 0 INDICATES OGEE = 0 INDICATES MORNING GLORY > 0 INDICATES CONTROLLED DISCHARGE
		NHTS	NUMBER OF PAIRS OF STAGE AREA DATA POINTS TO BE READ IN GROUP THREE
		WDIM	CHARACTERISTIC DIMENSIONS OF WEIR FOR WTP2 < 0 WDIM = LENGTH ft FOR WTP2 = 0 WDIM = RADIUS ft FOR WTP2 > 0 WDIM = FLOW CFS
3	3(F5.1, F8.0)	HAJ(R)	STAGE AREA DATA ABOVE
		ARJ(R)	FULL SUPPLY LEVEL, 3 PAIRS/CARD
4	6(F7.2)	CONC(K)	INITIAL VALUES OF PARAMETERS DESCRIBING WATER QUALITY

For SS and SETL S Equations (1) and (2), 22% reduction in two hours is somewhat arbitrarily assumed. Minimum values of 5 mg/l and 0.05 mg/l, respectively, are assumed. Equations (3), (4) and (5) are recognized as the Streeter Phelps equations (Velz, 1970). Whether such an approach (traditionally used for oxygen budgets in rivers) is valid in a reservoir situation is disputable and must await experimental evidence. The major cause for this concern is the difference in the mixing characteristics of rivers and reservoirs. The deoxygenation and reaeration coefficients recommended by McGauhey (1968) are used. The concentration of phosphorus (as ortho) and nitrogen are assumed to remain constant between storms (Equations (6) and (7)). This is a major simplification since factors such as the dissolved oxygen concentration, the presence of algae or aquatic vegetation and the chemistry of the sediments are ignored. For each hour reservoir storage is incremented (Equation (8)) using average monthly potential evaporation rates.

3) For the hour of runoff the efficiency of the stilling basin (in terms of suspended solids removal) is calculated using the equation:

$$EFF = 0.9 - 0.2 \times 10^{-6} \times OR^2, \text{ for } OR < 1000 \text{ U.S. gal/ft}^2\text{/d}$$
$$EFF = 0.7e^{0.00057(1000 - OR)}, \text{ for } 1000 < OR \text{ U.S. gal/ft}^2\text{/d}$$

where: EFF = efficiency, and
OR = overflow rate.

The assumed curve is shown in Figure 3. For each pollutant the effect of sedimentation is related to the efficiency EFF by:

$$SS_{rem} = (1 - EFF)\ SS_{IN} \quad (9)$$
$$SET\ S_{rem} = (1 - EFF)\ SET\ S_{IN} \quad (10)$$
$$BOD_{rem} = (1 - 0.5\ EFF)\ BOD_{IN} \quad (11)$$
$$N_{rem} = (1 - 0.3\ EFF)\ N_{IN} \quad (12)$$
$$PO_{4rem} = (1 - 0.2\ EFF)\ PO_{4IN} \quad (13)$$

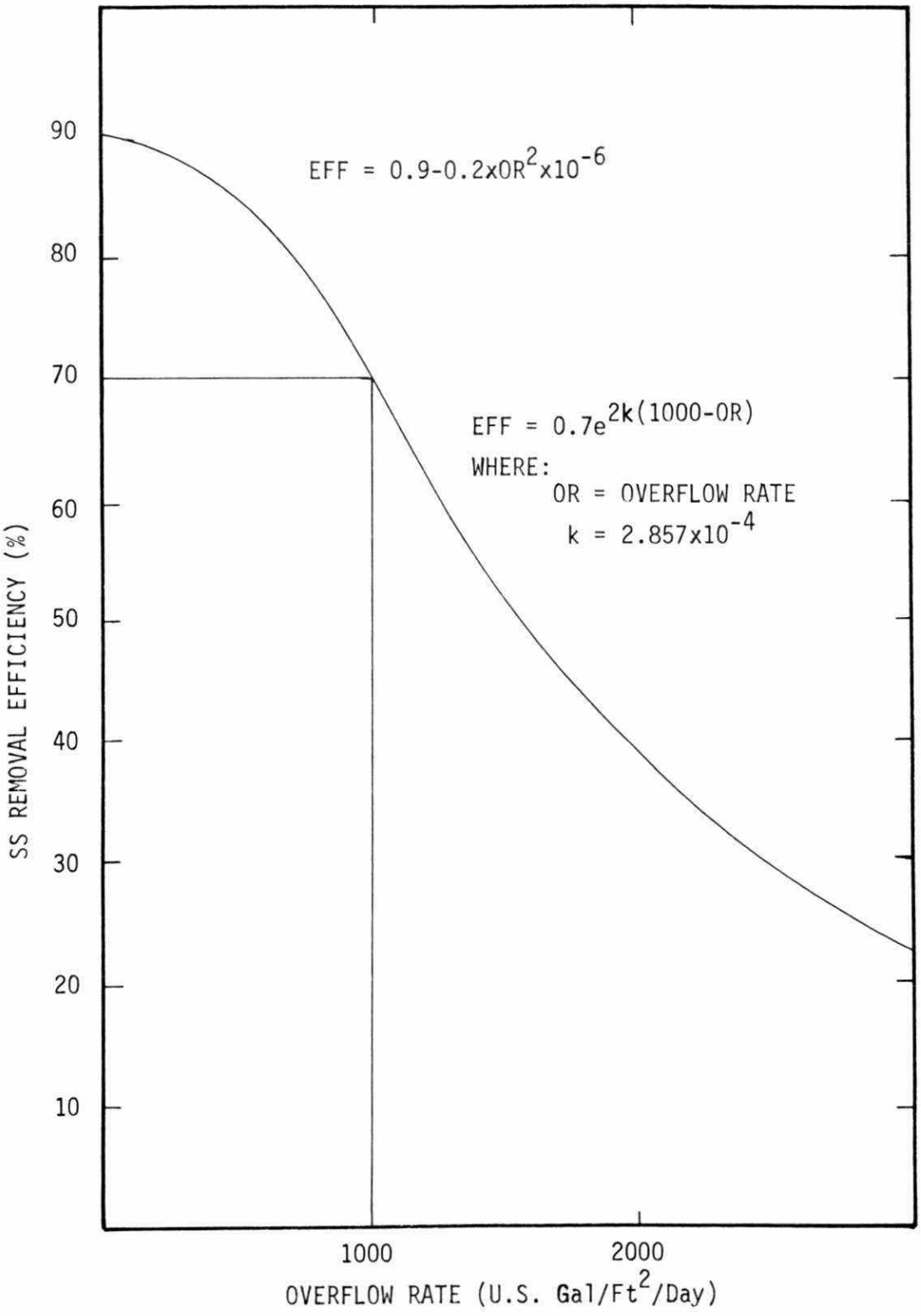


FIGURE 3. IDEALIZED PERFORMANCE CURVE FOR SETTLING BASIN

These assumed residuals are based on the performance typically achieved in primary clarifiers for sewage treatment (Heinke, 1973, and Metcalf and Eddy, 1972). The flow hydrograph is assumed to pass through the siltation basin without attenuation.

4) For the reservoir, the quality of the water is updated using the pollutant inputs from the stilling basin and assuming completely mixed conditions. The flow is routed using the well known puls technique (Wilson, 1969). Three discharge options are available, viz. the Ogee type spillway, Morning Glory type spillway, and a controlled constant discharge.

5) A counter variable records, for each month and for each pollutant, the accumulated number of hours in which the pollutant concentration has been within a specified range.

Output from the subroutine includes a frequency analysis of the stilling basin efficiency, an estimate of the volume of solids removed in the stilling basin and a monthly frequency analysis (for the six parameters SS, SETL S, BOD, N, PO_4, DO) of the reservoir water quality. If detailed event analysis is requested, inflow and outflow hydrographs and the concentrations of the six parameters in the outflow are printed.

The model as developed can and should be further improved. Capability for allowing chemical treatment, for including intentional drawdown policy, for reading in user options for constants (such as monthly temperature, pollutant categories and decay coefficients) and for simulating bacterial contamination would be immediate objectives. It is hoped that future work will be done at the University of Toronto (or elsewhere) on MIKE and that ultimately the routine will be released for general use as part of STORM.

4.2 University of Toronto Experience

The practical application of STORM requires three temporary data sets to store information for the quality report, for the pollutograph report and for the erosion report. These temporary data sets are passed at the end of the first job step (the STORM computation) to a second step which, programmed by the user, must print out the contents of the

temporary files. The STORM program does not itself produce this print-out.

Progressing from this stage, rainfall data for the years 1961 - 1974 (some ten thousand cards) were obtained from the Atmospheric Environment Service (AES) of Fisheries and Environment Canada. Many of the data cards contained negative rainfalls, alphabetic rainfalls and over-punches and the entire set had to be sorted before use.

The STORM program, as obtained from the Ontario Ministry of the Environment, was set up to read United States rainfall cards and before the edited AES data could be used, a change of format, presented below, was necessary:

```
FOR U.S. DATA CARDS        2120 FORMAT (2X, I6, 24I3)                  1915
FOR CANADIAN DATA CARDS    2120 FORMAT (9X,I6,5X,12I3,/,20X,12I3)      1915
```

5. MEADOWVALE TEST SITE

5.1 General

Meadowvale is a "new town" presently under construction in Mississauga, Ontario. The town comprises some 300 acres and the population is expected to reach 65,000 after completion in 1985. A simplified plan of the development is shown in Figure 4. Two dams are planned as features of a connected green belt. Construction on the first of these in Meadowvale West was to start in 1976. The future lake and its catchment is the prototype which has been examined in this study.

Most of the 245-acre catchment will be residential. A portion of the catchment is outside of Meadowvale proper (the area to the west of Winston Churchill Boulevard). It is assumed that this area will ultimately be residential. Prior to development the land was used for agriculture; originally, however, it would have been forested.

The 12 acre dam and stilling basin facility will be used for non-body contact activities (boating, fishing etc.). The water quality of the dam basin will thus be the major determinant of its recreational value. Discharge from the dam is to be channelled to the Credit River, approximately two miles distant.

It is expected that the Meadowvale approach to development (i.e., the integration of water-based recreational facilities into "completely" planned communities) will dominate planning concepts for the next 20 years.

5.2 Discretization for SWMM and STORM

The input data requirements for simulation using SWMM are complex. The catchment must be discretized and a system of pipes and junctions representative of the actual drainage structure must be used to connect each subcatchment. Three conditions were modelled using SWMM, i.e., undeveloped, developing and fully developed conditions. The drainage system designed for Meadowvale will relocate minor watershed boundaries, making a comparison of pre and post-development conditions for subcatchments difficult. To resolve this problem, pre and post-development watershed boundaries for the dam were assumed to coincide with those for developed conditions.

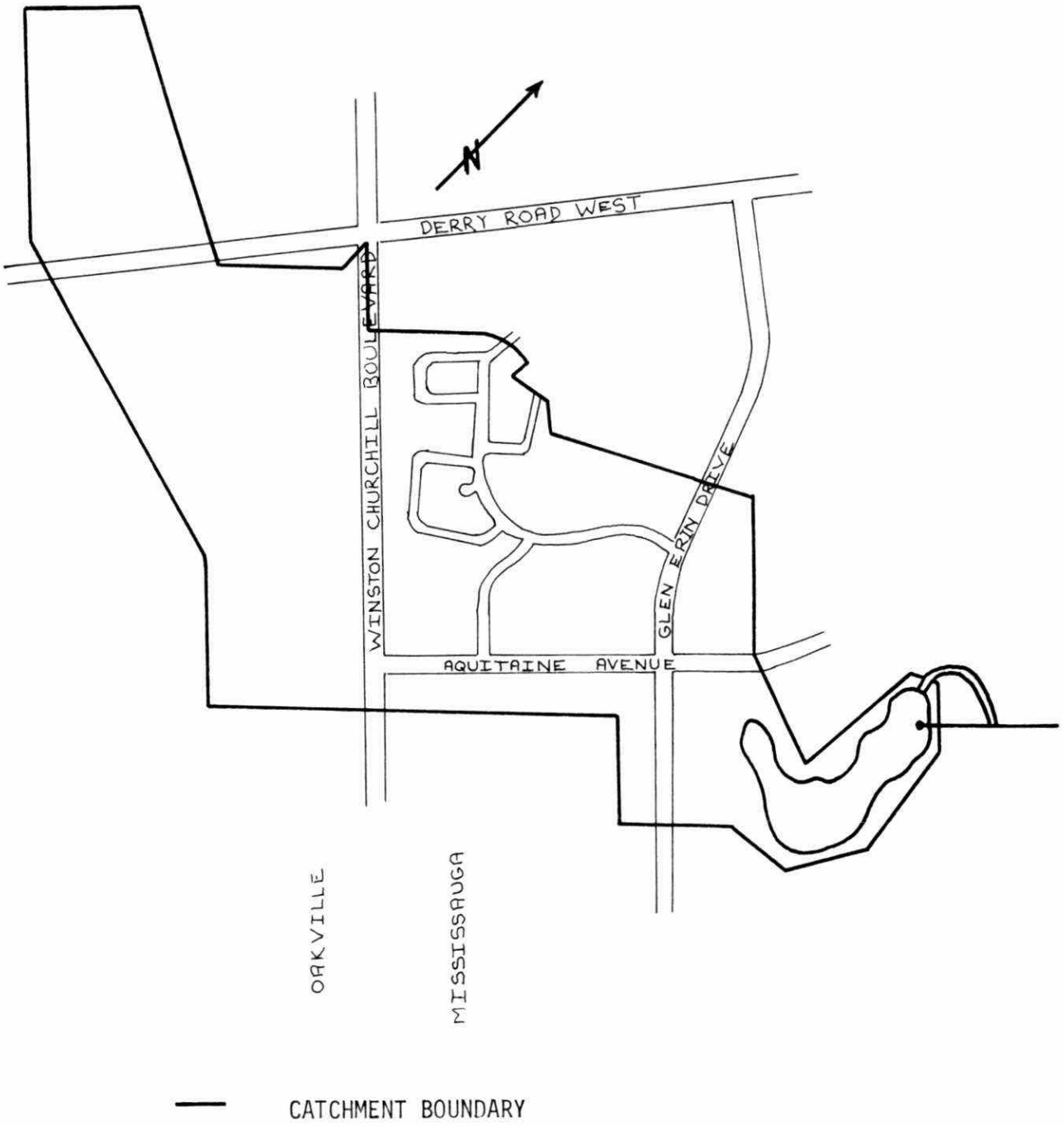


FIGURE 4. PLAN OF THE MEADOWVALE WEST CATCHMENT

For STORM, data requirements are much simpler. The entire catchment is lumped and no transport system is used. Conditions before and after development (as for SWMM) were simulated and the required physical data are shown in Table 2.

5.3 Rainfall Data

Rainfall data from the Atmospheric Environment Service (AES) station at Malton, ten miles from Meadowvale, were used for both SWMM and STORM simulations. No areal correction factors were applied and snowmelt was not considered.

For STORM, 14 years of hourly rainfall records (1961-1974) were used. Since STORM gives a continuous simulation, the effects of evaporation on depression storage regeneration must be considered. The respective data, also provided by AES, are shown in Table 3.

For SWMM, continuous recorded rainfall measurements for 1974 were used to develop ten-minute interval hyetographs. All events (an event is defined in this case by 12 hours of no rain prior to the storm) with a total rainfall of greater than 0.2" were simulated. Events longer than 33 hours, the maximum possible simulation for ten minute hyetographs, were contracted. This may give a small overestimate of runoff. Events of periods of no rain greater than two hours were contracted to avoid difficulties arising from regeneration of excess depression storage by infiltration during breaks in rainfall (Orlob, 1974).

5.4 Quality Simulation Data

SWMM and STORM use analogous procedures for determining runoff quality. The required data are:

1) the daily rate of dust and dirt accumulation in lb/100 ft of curb for each land use;

2) the pounds of specific pollutant per 100 lb of dust and dirt (STORM has the facility to model nonurban areas, in which case loadings are reported directly in pounds of pollutant per acre); and,

3) catchment parameters such as the length of gutters, the number of catch basins, the frequency of streetsweeping,

TABLE 2. PHYSICAL CATCHMENT DATA FOR STORM SIMULATIONS

1. UNDEVELOPED CONDITIONS

NON-URBAN WATERSHED DATA

LAND AREA = 241 ACRES (97 HECTARES)
RUNOFF COEFFICIENT = 0.25
DEPRESSION STORAGE = 0.1 IN (2.5mm)

URBAN WATERSHED DATA

LAND AREA = 1 ACRE
LAND USE = SINGLE FAMILY RESIDENTIAL
RUNOFF COEFFICIENT
(PERVIOUS) = 0.15 (75% OF AREA)
(IMPERVIOUS) = 0.9
DEPRESSION STORAGE = 0.05 IN (1.3mm)
GUTTER LENGTH = 2 FT/ ACRE (1.5m/Ha)

2. DEVELOPED CONDITIONS

URBAN WATERSHED DATA

LAND AREA = 244 ACRES (98 HECTARES)
RUNOFF COEFFICIENT
(PERV AREA) = 0.15
(IMPERV AREA) = 0.9
DEPRESSION STORAGE = 0.05 IN (1.3mm)

LAND USE	% OF LAND AREA	PERCENT IMPERV	GUTTER LENGTH FT/A	GUTTER LENGTH M/Ha
SINGLE	65.2	30.0	300.0	226.0
MULTPL	22.9	65.0	300.0	226.0
COMMCL	11.9	85.0	400.0	301.2

TABLE 3. MONTHLY AVERAGE EVAPORATION RATES AND TEMPERATURES FOR MALTON WEATHER STATION (AES)

MONTH	MEAN TEMP ^{o}C	MEAN EVAP	
		inches	mm
JANUARY	0	0	0
FEBRUARY	0	0	0
MARCH	6.3	0.3	8
APRIL	6.4	3.6	91
MAY	12.0	4.8	122
JUNE	18.2	5.7	145
JULY	20.7	6.9	175
AUGUST	20.0	4.8	122
SEPTEMBER	15.7	3.6	91
OCTOBER	9.8	1.8	46
NOVEMBER	4.5	1.2	30
DECEMBER	0	0	0

the efficiency of streetsweeping and (for SWMM) the number of dry days prior to the event.

Data on loading rates of dust and dirt and on the component fractions of the dust and dirt were not available for Canadian conditions; hence, the values shown in Table 4, which are based on the APWA study in Chicago (American Public Works Association, 1969), were assumed. Work is presently being done under the aegis of the Canada-Ontario Agreement to establish this information for Canada and should be completed shortly.

Quantitative values for the various catchment parameters were obtained from a variety of sources, including the Public Works Department of the City of Mississauga, Project Planning Associates Limited (the project consultants) and a personal inspection of the site.

The regression equations developed by Colston and Tafuri (1975) were used to give a second estimate of runoff quality. Flow hydrographs obtained from SWMM provided the necessary input data (i.e. flow rate and time from start of storm).

5.5 Reservoir Data

Input data for the reservoir simulation using subroutine MIKE are presented in Table 5. The initial quality of dam water was arbitrarily chosen. For a long-term simulation, such as was done for Meadowvale, the choice is unimportant.

TABLE 4. ASSUMED POLLUTANT LOADING RATES IN SWMM AND STORM

LANDUSE	D&D RATE LB /100'/D	LBS POLLUTANT / 100 LB OF D&D[a]							COLIFORM MPN/gm OF D&D
		SUSP S[c]	SETL S[c]	BOD[c]	COD	N[c]	PO_4[c]	GREASE	
SINGLE FAMILY RES.	0.7	11.1	1.1	0.5	4.0	0.048	0.005	0.1	1.3×10^6
MULTPL FAMILY RES.	2.3	8.0	0.8	0.36	4.0	0.061	0.005	0.1	2.7×10^6
COMMER-CIAL	3.3	17.0	1.7	0.77	3.9	0.041	0.007	0.1	1.7×10^6
INDUST-RIAL	4.6	6.7	0.7	0.3	4.0	0.043	0.003	0.1	1.0×10^6
OPEN-PARK	1.5	11.1	1.1	0.5	2.0	0.005	0.001	0.1	0
NON URBAN[b]	N/A	0.023	0.02	0.03	-	0.01	0.003	-	-

a MOST VALUES ARE BASED ON 1969 APWA REPORT

b THIS LANDUSE IS AN OPTION IN STORM ONLY, UNITS ARE LBS/ACRE/DAY.

c POLLUTANTS SIMULATED IN STORM.

CONVERSION FACTORS: 1LB/100 FT = 15gm/m, 1LB/100LBS = 10mg/gm, 1LB/ACRE = 1.1Kg/HECTARE

TABLE 5. INPUT DATA FOR RESERVOIR SIMULATION USING SUBROUTINE MIKE

1. SILTATION BASIN

   VOLUME AT WEIR LEVEL = 474200 FT^3 ($13427m^3$)

   AREA AT WEIR LEVEL = 39520 FT^2 ($3671m^2$)

3,560 9/

2. DAM

   VOLUME AT F.S.L. (928.2') = 4.85×10^6 FT^3 ($1.37 \times 10^5 m^3$)

HEIGHT ABOVE WEIR		AREA	
FT	m	FT^2	m^2
0	0	455200	42289
1.8	0.54	481920	44772
3.8	1.15	512480	47610

3. SPILLWAY

   DROP-INLET TYPE

   CHARACTERISTIC DIMENSION = RADIUS = 8' (2.4m)

4. INITIAL QUALITY OF DAM WATER

   CONC (1) = S.S. = 20mg/l

   CONC (2) = SETL. S. = 5mg/l

   CONC (3) = BOD = 10mg/l

   CONC (4) = N = 1mg/l

   CONC (5) = PO_4 = 0.1mg/l

   CONC (6) = DISSOLVED OXYGEN = 8mg/l

6. HYDROLOGICAL SIMULATION

6.1 General

The SWMM model was run for urbanized conditions for all storms of 1974 with total rainfalls greater than 0.2" (5 mm). The statistics for each storm are listed in Table 6. From this series, three storms were chosen for detailed analysis, i.e., to simulate undeveloped conditions (allowing comparative analysis of urbanization effects), to study the advantages of storage and to investigate erosion. These storms were:

1) Storm of 4th March - A long (13-hr) frontal storm (1.2"/30 min).
2) Storm of 16th June - The largest (10-hr) storm of the year (2.25"/57 mm).
3) Storm of 3rd July - A short convective thunderstorm (1.3"/33 mm in 3 hr) with the largest ten-minute intensity (3" per hour/76 mm per hour).

The STORM model was run for all storms from 1961 - 1974, inclusive, for both developed and undeveloped conditions.

Comparison of predicted hydrographs using SWMM and STORM are presented in Figures 5-10. For urbanized (developed) conditions, two features were noted:

1) Peak flows predicted by SWMM were approximately 45% greater than those predicted by STORM. This result was not surprising since STORM, by using hourly rainfall data, must consistently underestimate peaks from shorter duration effects. The model however, was not designed for accurate event prediction.

2) The total runoff predicted by STORM for each storm was approximately 10% greater than that predicted by SWMM. This very small difference is a calibration problem requiring field data for its solution. Balancing of the SWMM and STORM results would magnify the peak discrepancy discussed above.

For nonurbanized (undeveloped) conditions, peak flows as well as total runoffs predicted by STORM were significantly greater than those predicted by SWMM. A detailed analysis of this is given in Table 7.

TABLE 6. STATISTICS FOR 1974 STORMS SIMULATED USING SWMM

STORM OF	TOTAL RAINFALL IN	mm	MAXIMUM 10 MINUTE INTENSITY IN/HR	mm/HR	DURATION HOURS
JAN 22	0.21	5.3	0.18	4.5	7
JAN 26	0.64	16.2	0.78	19.8	4
MAR 4	1.20	30.4	0.48	12.2	13
APR 1	0.48	12.2	0.84	21.3	2
APR 3	1.08	27.4	0.6	15.2	6
APR 12	0.28	7.1	0.36	9.1	5
APR 14	0.48	12.2	1.14	29.0	3
APR 22	0.51	13.0	0.36	9.1	6
MAY 5	0.26	6.6	0.30	7.6	3
MAY 8	0.78	2.0	0.18	4.6	14
MAY 15	0.21	5.3	0.36	9.1	3
MAY 16	2.25	57.2	2.46	6.2	10
MAY 28	0.43	10.9	0.54	1.4	7
JUN 13	0.34	8.6	0.42	1.1	4
JUN 15	0.90	22.9	1.98	50.3	9
JUN 19	1.20	30.5	0.96	24.4	13
JUN 21	0.65	16.5	1.5	38.1	2
JUL 3	1.30	33.0	3.03	76.9	3
JUL 29	0.23	58.4	0.36	9.1	5
JUL 30	0.52	13.2	0.90	2.3	5
SEP 2	0.44	11.2	0.18	4.6	11
SEP 12	0.26	6.6	0.3	7.6	4
SEP 28	0.76	19.3	0.24	6.1	14
OCT 14	0.32	8.1	0.30	7.6	5
NOV 5	0.47	11.9	0.42	10.7	6
NOV 12	0.44	11.1	0.12	3.0	12
NOV 13	0.28	7.3	0.24	6.1	4
NOV 20	1.20	30.5	0.36	9.1	22

TOTAL SIMULATED RAINFALL = 18.1" (460mm)
TOTAL RECORDED RAINFALL = 25.1" (638mm) (FOR 1974)

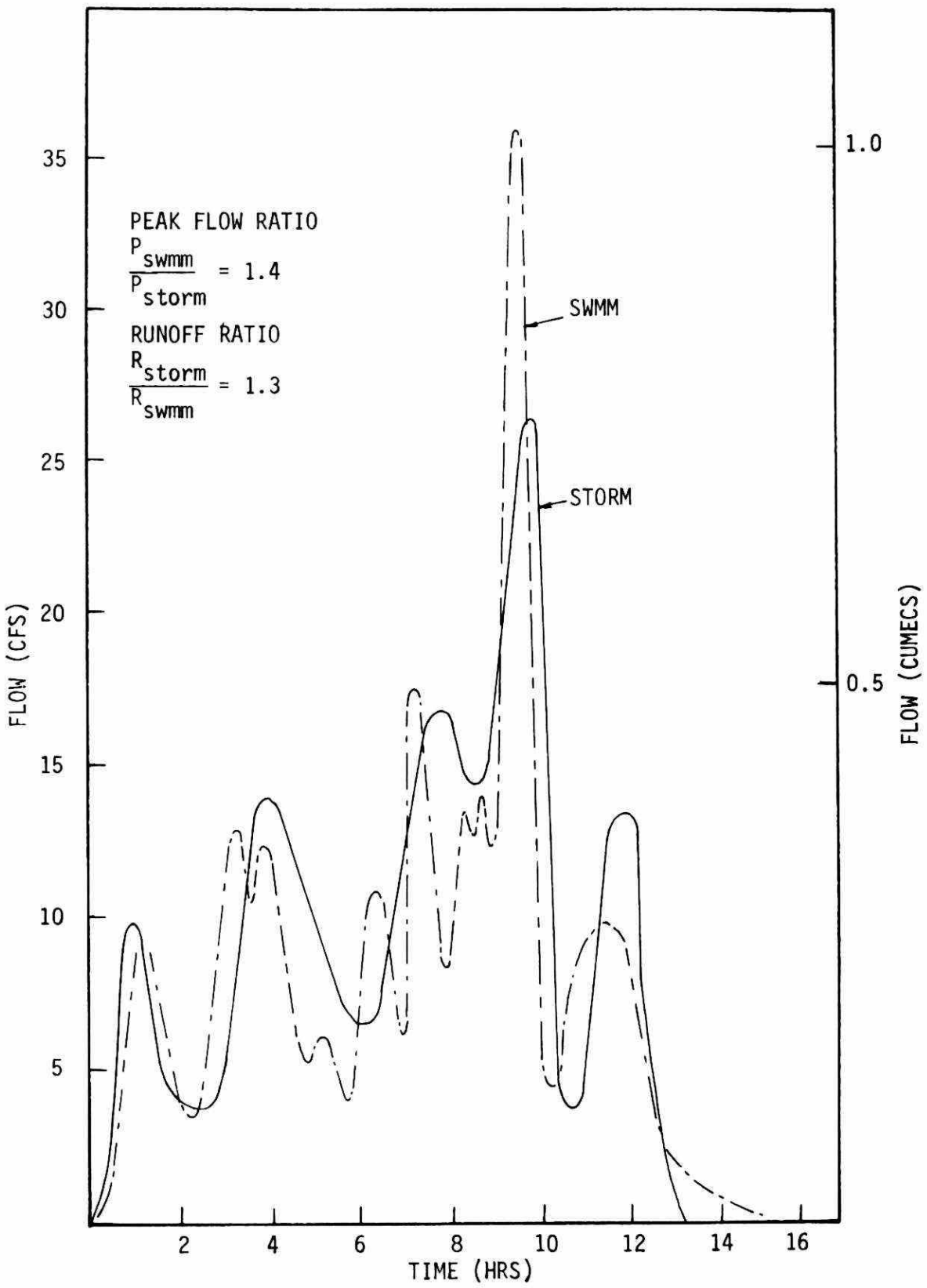


FIGURE 5. COMPARISON OF SIMULATED HYDROGRAPHS USING SWMM AND STORM FOR DEVELOPED CONDITIONS (STORM OF MARCH 4, 1974)

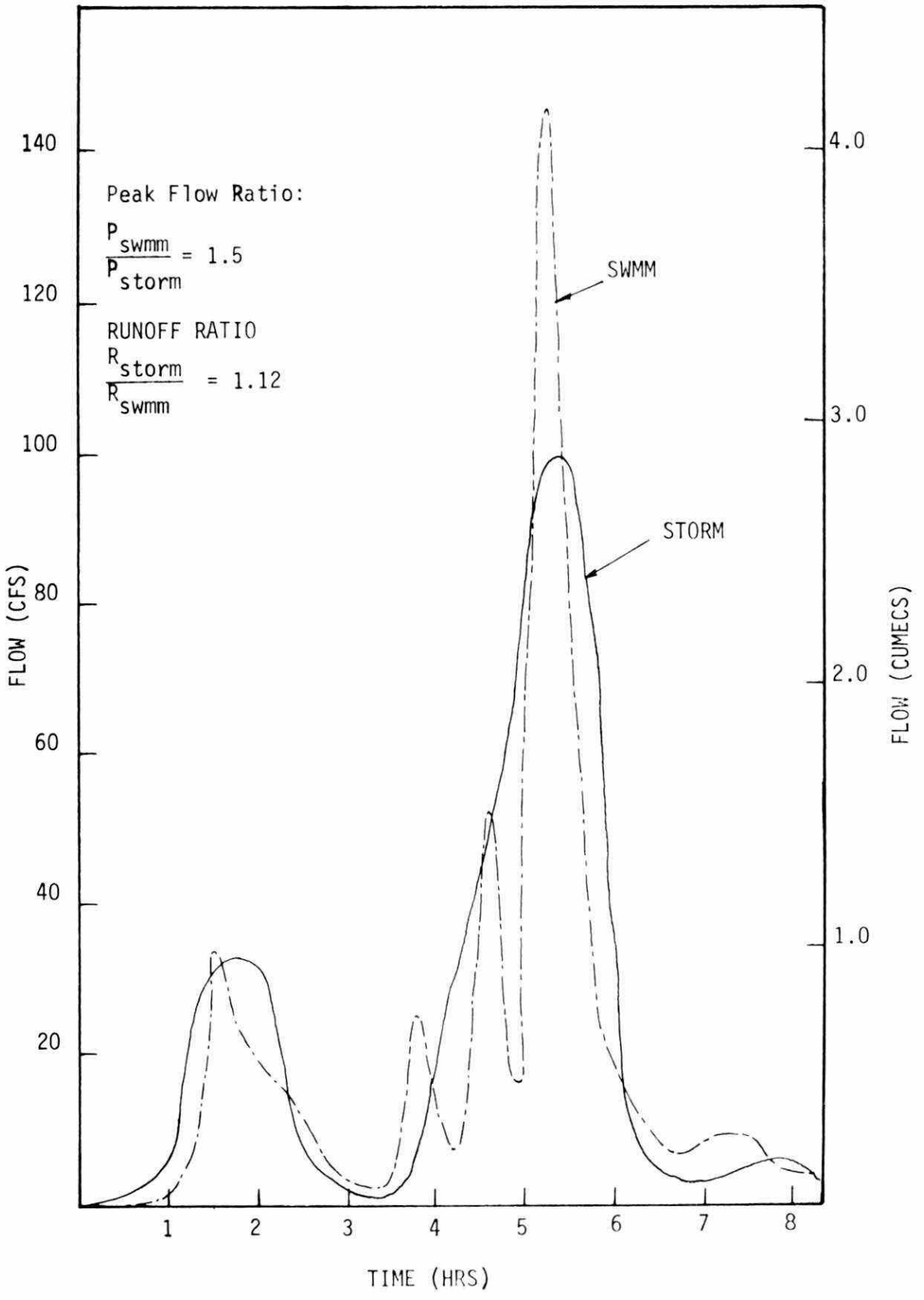


FIGURE 6. COMPARISON OF SIMULATED HYDROGRAPHS USING SWMM AND STORM FOR DEVELOPED CONDITIONS (STORM OF MAY 16, 1974)

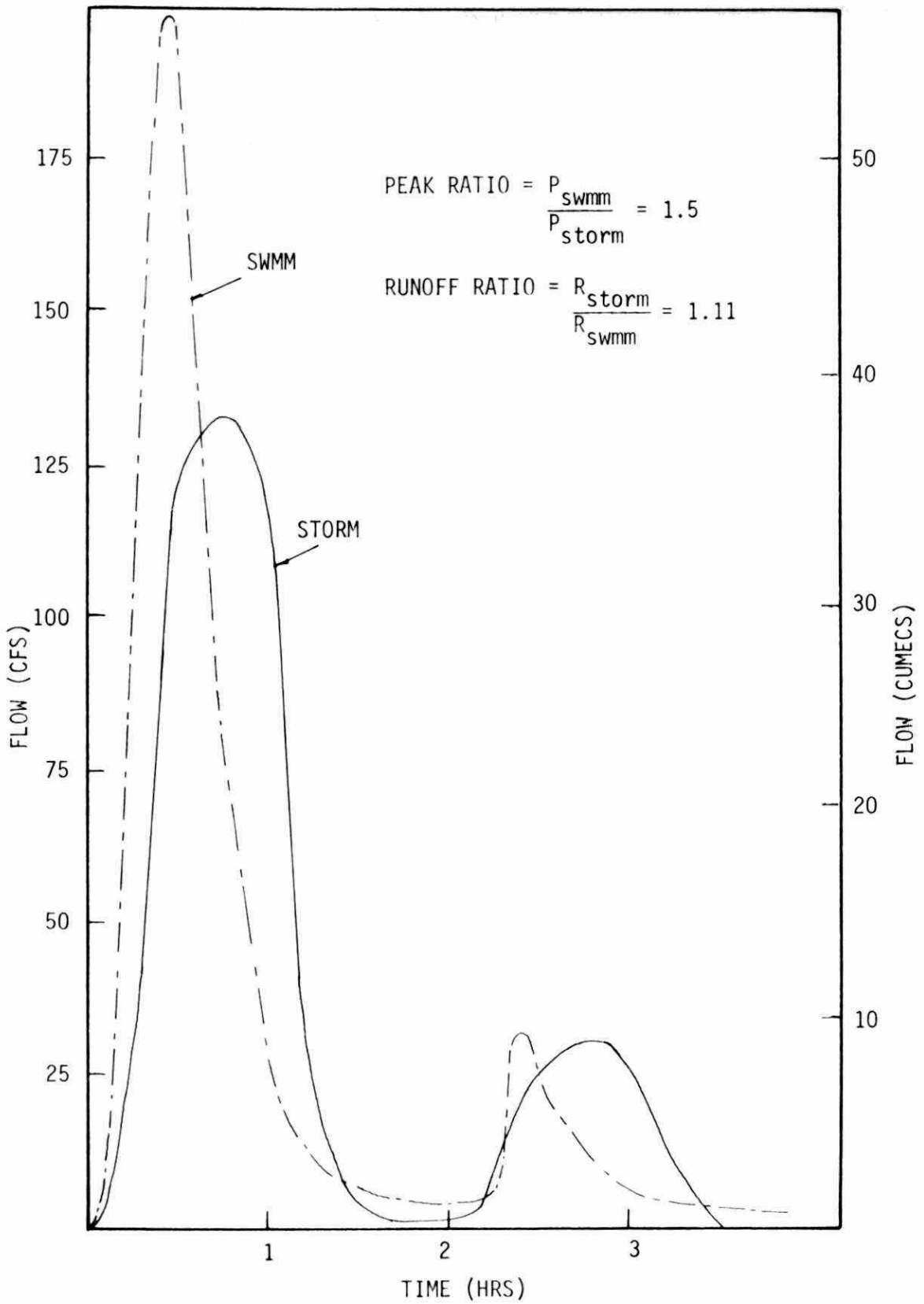


FIGURE 7. COMPARISON OF SIMULATED HYDROGRAPHS USING SWMM AND STORM FOR DEVELOPED CONDITIONS (STORM OF JULY 3, 1974)

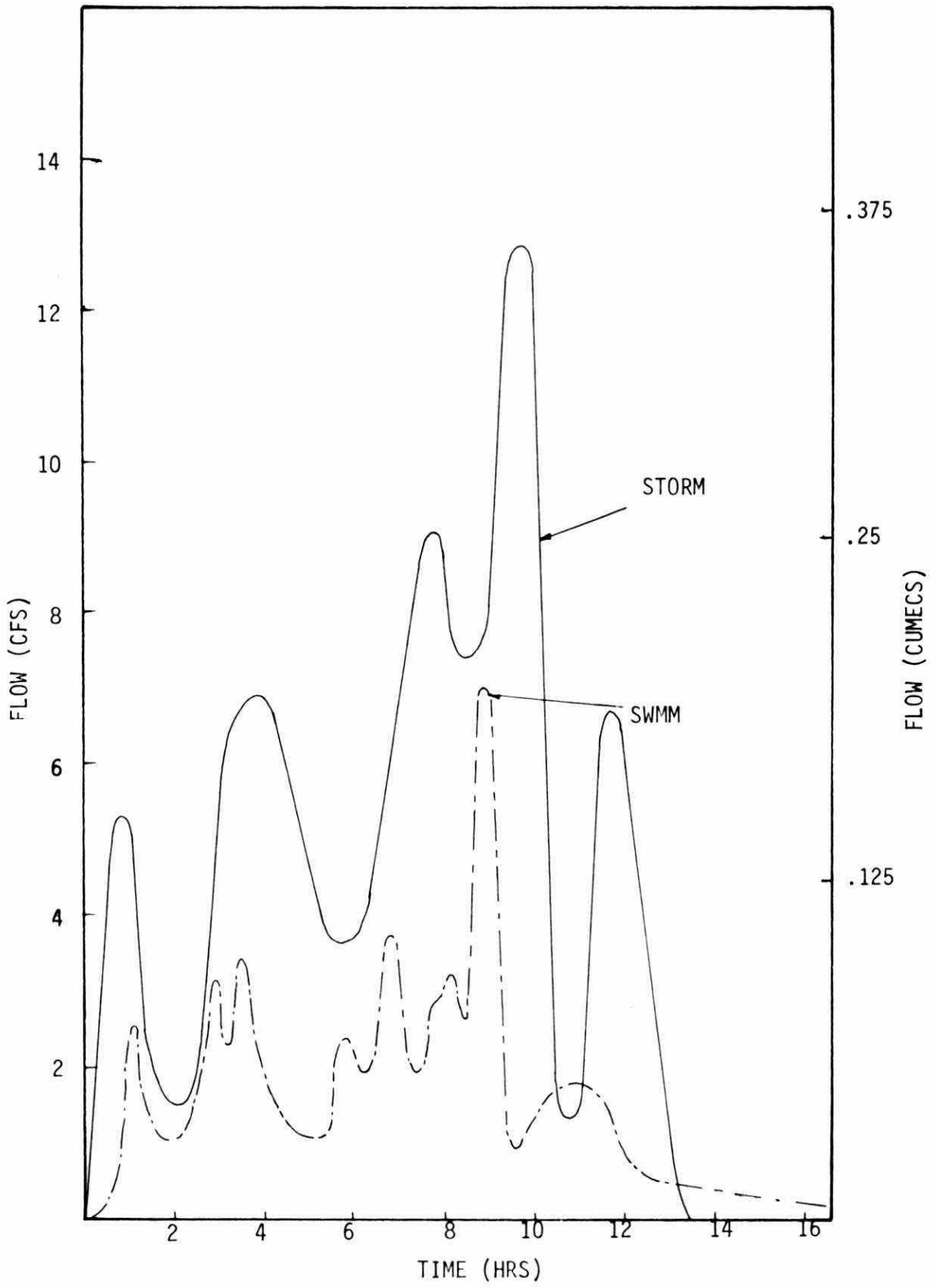


FIGURE 8. COMPARISON OF SIMULATED HYDROGRAPHS USING SWMM AND STORM FOR UNDEVELOPED CONDITIONS (STORM OF MARCH 4, 1974)

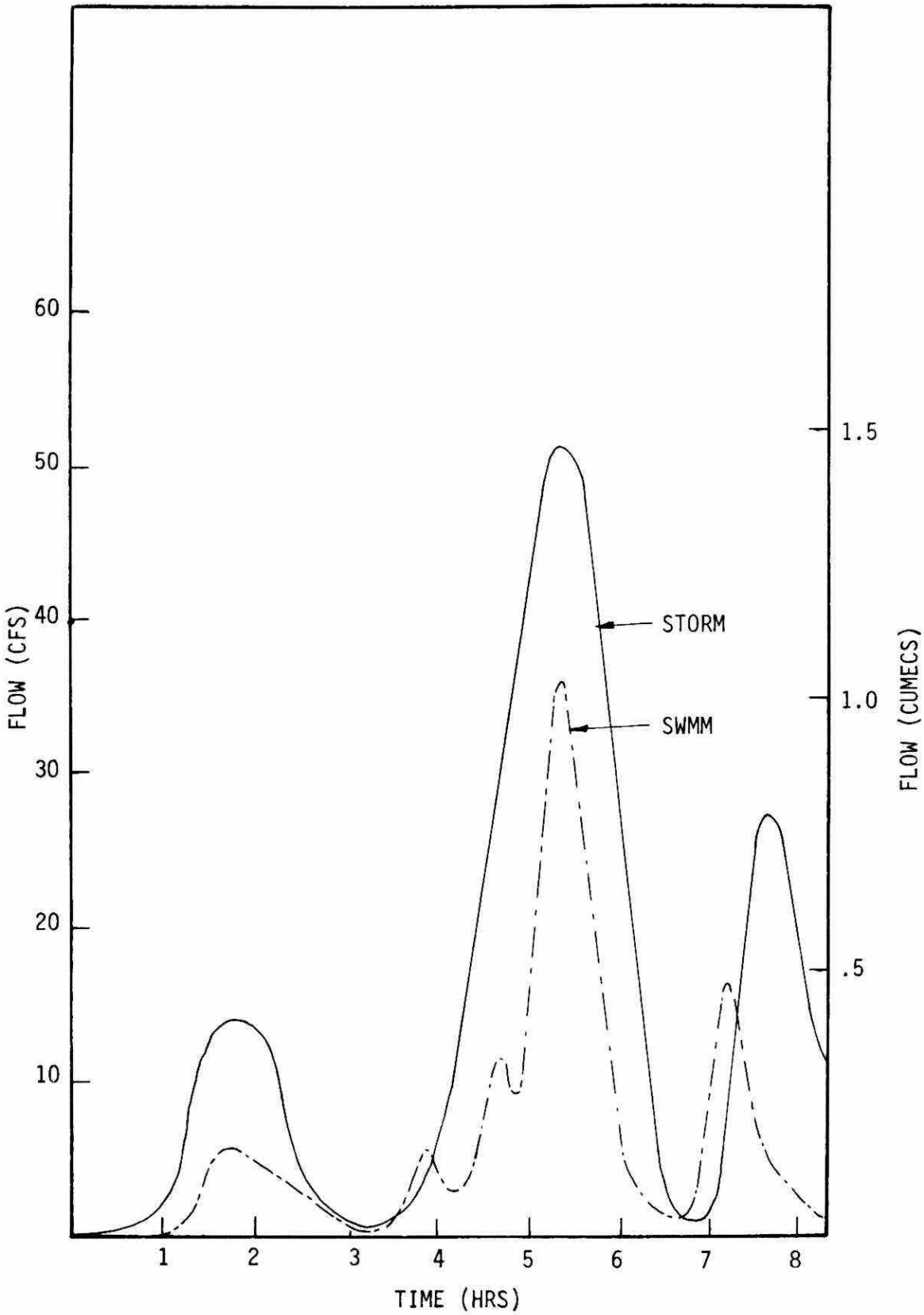


FIGURE 9. COMPARISON OF SIMULATED HYDROGRAPHS USING SWMM AND STORM FOR UNDEVELOPED CONDITIONS (STORM OF MAY 16, 1974)

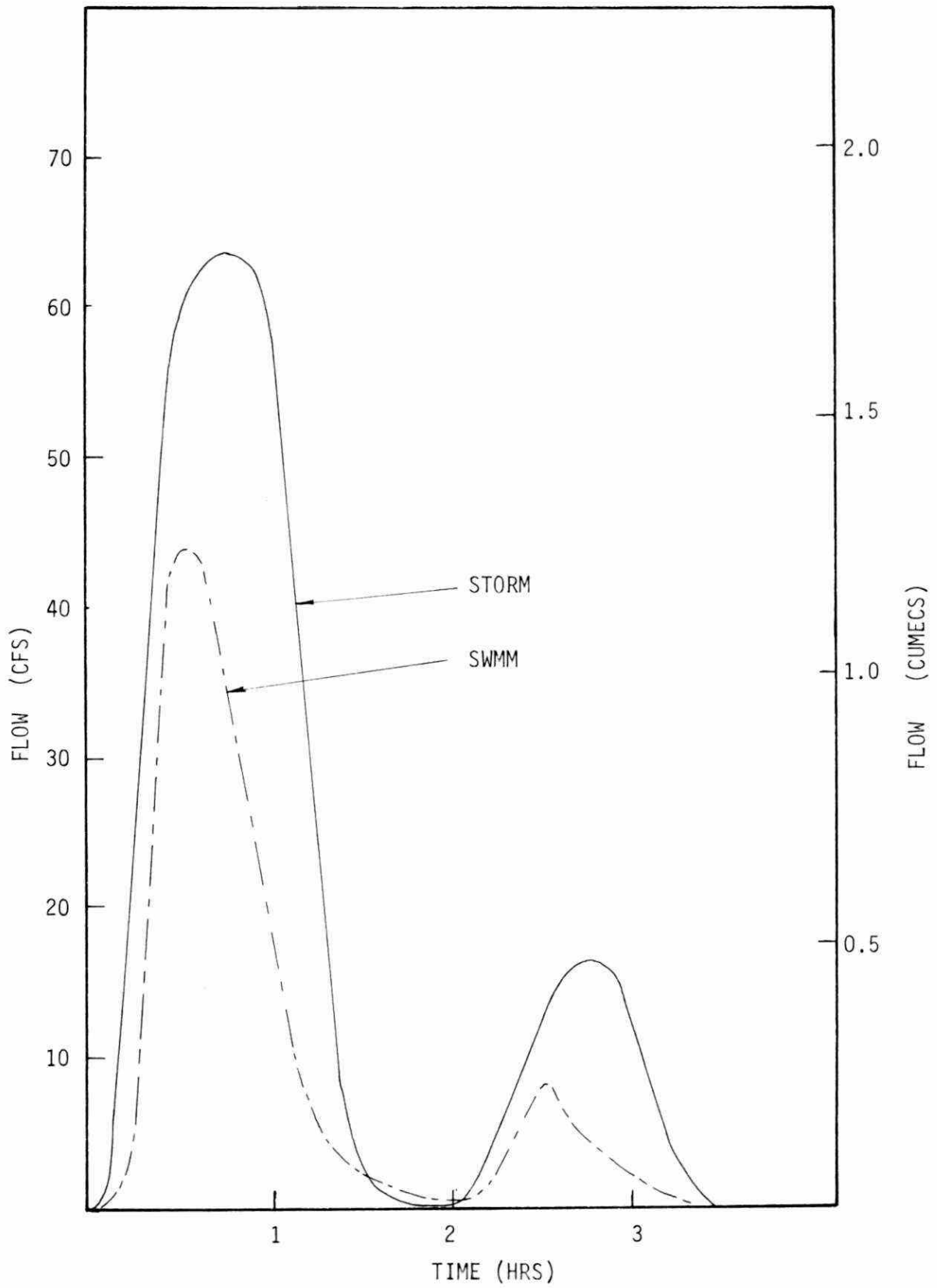


FIGURE 10. COMPARISON OF SIMULATED HYDROGRAPHS USING SWMM AND STORM FOR UNDEVELOPED CONDITIONS (STORM OF JULY 3, 1974)

TABLE 7. COMPARISON OF PREDICTED HYDROGRAPHS FOR UNDEVELOPED CONDITIONS USING SWMM AND STORM

STORM	MARCH 4	MAY 16	JULY 3
DURATION (HOURS)	13	10	3
RAINFALL (IN)	1.19	2.25	1.3
SWMM:			
RUNOFF (IN)	0.11	0.25	0.21
PEAKFLOW (CFS)	7.0	33.0	43.3
STORM:			
RUNOFF (IN)	0.29	0.53	0.30
PEAKFLOW (CFS)	12.8	50.1	59.3
$\frac{\text{RUNOFF}_{storm}}{\text{RUNOFF}_{swmm}}$	2.8	2.1	1.5
$\frac{\text{PEAK}_{storm}}{\text{PEAK}_{swmm}}$	1.8	1.5	1.4

Not only did STORM predict a greater runoff yield, but the prediction was different for each storm, the maximum difference occurring with the longest storm (March 4th). An explanation of this apparent anomaly is to be found in the way the two models consider losses.

STORM assumes a depression storage and any rainfall in excess of this storage is available for runoff, but not necessarily converted into runoff dependent on the value of the runoff coefficient. SWMM computes losses due to depression and infiltration explicitly. Thus, if the assumed infiltration rates used in SWMM are too large, an underestimate of runoff approximately proportional to the storm length as observed would be expected. In addition, the runoff coefficient assumed for STORM may be too large. Again this is a calibration problem requiring adjustment of model parameters (e.g. infiltration rates, percent imperviousness for SWMM, and runoff coefficients and depression storage for STORM) to fit measured flows. Once the runoff predictions agreed, the peak ratio shown above would likely become fractional, i.e., STORM would underestimate peaks.

The predictions were considered acceptable for a comparison of the hydrological effects of urbanization and storage.

6.2 Hydrological Effects of Urbanization

Comparative studies of urban versus rural drainage basins indicate that as the relative magnitude of flood peaks increases, the ratio of urban peak flow rate to rural peak rate declines, the effect of urbanization being more pronounced for the more frequent occurrences. For large storms, infiltration losses are a small proportion of the total rainfall and the catchment behaves as if it were impervious.

At Meadowvale the effects of urbanization as predicted by STORM are summarized in Table 8. The annual runoff is seen to increase by a factor of 2.15. For specific events, the ratio of nonurban peak to urban peak (for 15 large events) was calculated to be constant at 1.95, the same as the ratio of the runoff coefficients. This is not surprising since STORM uses a constant runoff coefficient; however, it means that one cannot derive any relationship between storm frequency and the peak flow increase due to urbanization using STORM results.

TABLE 8. STORM PREDICTIONS PRE AND POST-DEVELOPMENT

Average Annual Statistics for 14 Years of Record

For the Period Beginning Apr. 9, 1961 and Ending Dec. 12, 1974

Non-Urbanized Conditions

Number of Events = 69.0
Number of Overflows = 69.0

Total Precipitation on Watershed	21.67 inches
Total Runoff from Watershed	4.09 inches
Overflow to Receiving Water	4.10 inches
Initial Overflow to Receiving Water	2.35 inches

Fraction of Rainfall = 0.19
Fraction of Rainfall = 0.19, of Runoff = 1.00
Fraction of Rainfall = 0.11, of Runoff = 0.57

Average Annual Statistics for 14 Years of Record

For the Period Beginning Apr. 9, 1961 and Ending Dec. 12, 1974

Urbanized Conditions

Number of Events = 69.1
Number of Overflows = 69.1

Total Precipitation on Watershed	21.67 inches
Total Runoff from Watershed	8.85 inches
Overflow to Receiving Water	8.85 inches
Initial Overflow to Receiving Water	5.47 inches

Fraction of Rainfall = 0.41
Fraction of Rainfall = 0.41, of Runoff = 1.00
Fraction of Rainfall = 0.25, of Runoff = 0.62

The reason for the difference in the peak flow rate ratio and the runoff ratio is the depression storage. The depression storage assumed (0.1" for undeveloped and 0.05" for developed conditions) determines a critical value for total storm rainfall below which no runoff occurs. This implies that for some storms between (0.05" and 0.1") there is effectively an infinite increase in runoff.

Using SWMM, the effect of urbanization on specific events is illustrated in Figures 11-13. For the three storms, the following information was derived.

STORM OF	TOTAL RAINFALL in	15 MIN. RAINFALL in/hr	R.P.* years	BEFORE URB.		AFTER URB.		R_A / R_B	P_A / P_B
				RUNOFF in	PEAK cfs	RUNOFF in	PEAK cfs		
4/3/74	1.2	0.44	1	0.11	7	0.50	34.5	4.3	4.9
16/5/74	2.25	1.96	1	0.25	33	0.94	135.1	3.8	4.1
3/7/74	1.3	2.56	3	0.21	45	0.55	193.7	2.6	3.9

* Return periods based on maximum 15 minute rainfall intensity and the IDF curve for Malton

One weakness of such a comparison is that the storms have different temporal patterns. Ideally, to study the effects of urbanization on storms of different return periods, linearly proportional storms should be used (i.e., storms should be of the same length and pattern, the only difference being in the rainfall intensities).

Generally, these results followed the expected pattern; the effects of urbanization were most pronounced for the March 4th storm. A study of the literature indicates that the predicted increases in peak flow may be excessive. Rantz (Shubinski, 1974), using regression analysis to derive flood frequency equations, developed a factor to account for urbanization. For catchments similar to Meadowvale (i.e., 40% impervious and completed sewered), he predicted an increase of 2.5 in the peak flow for a one-year storm, compared to the 3.8 predicted by the SWMM for the July 3rd storm. In a survey on the effects of urbanization on run-off, Rao et al (1972) found increases in peak flow ranging from 1.5 to 3.0.

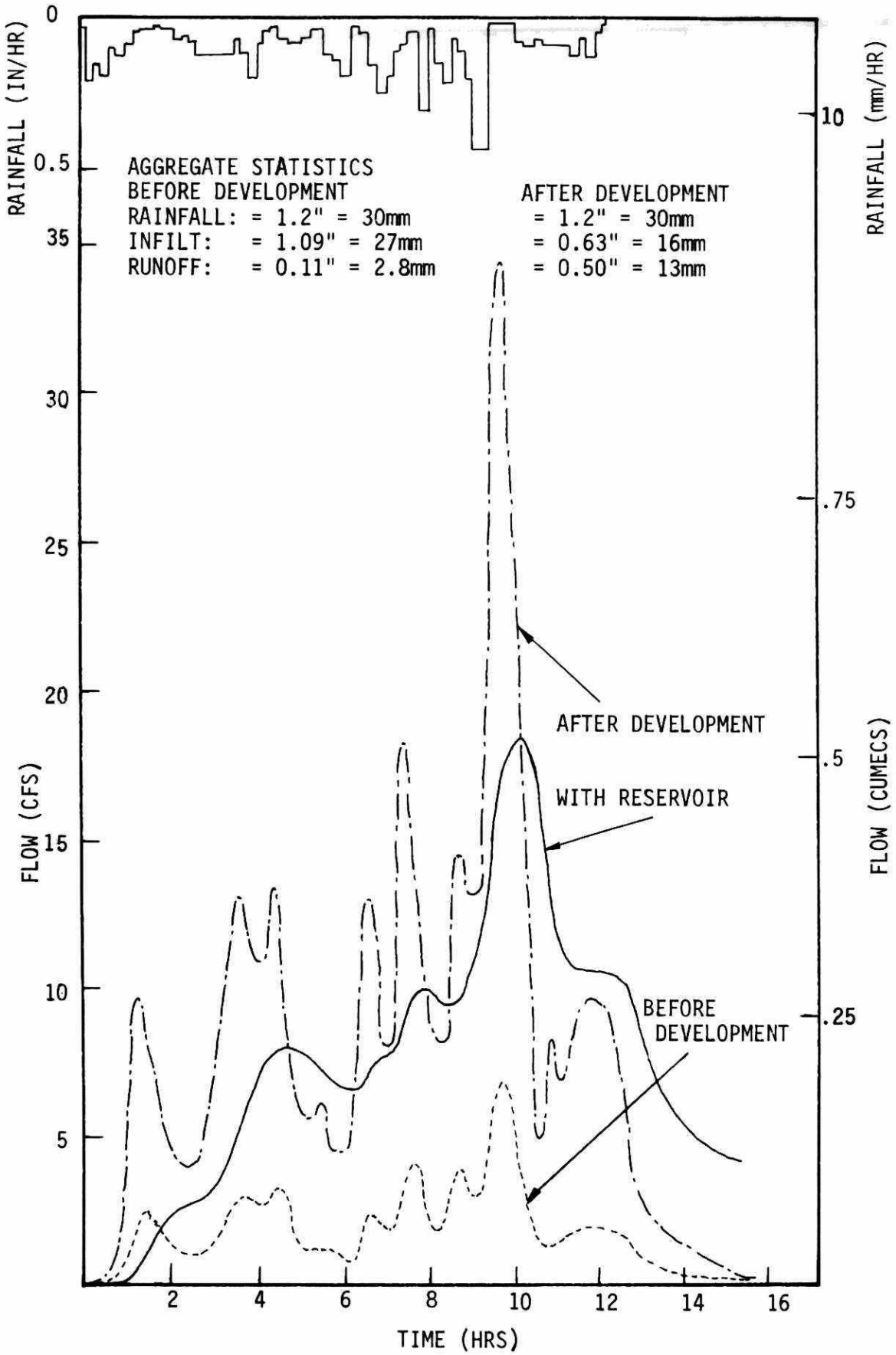


FIGURE 11. SWMM SIMULATION HYDROGRAPHS (STORM OF MARCH 4, 1974)

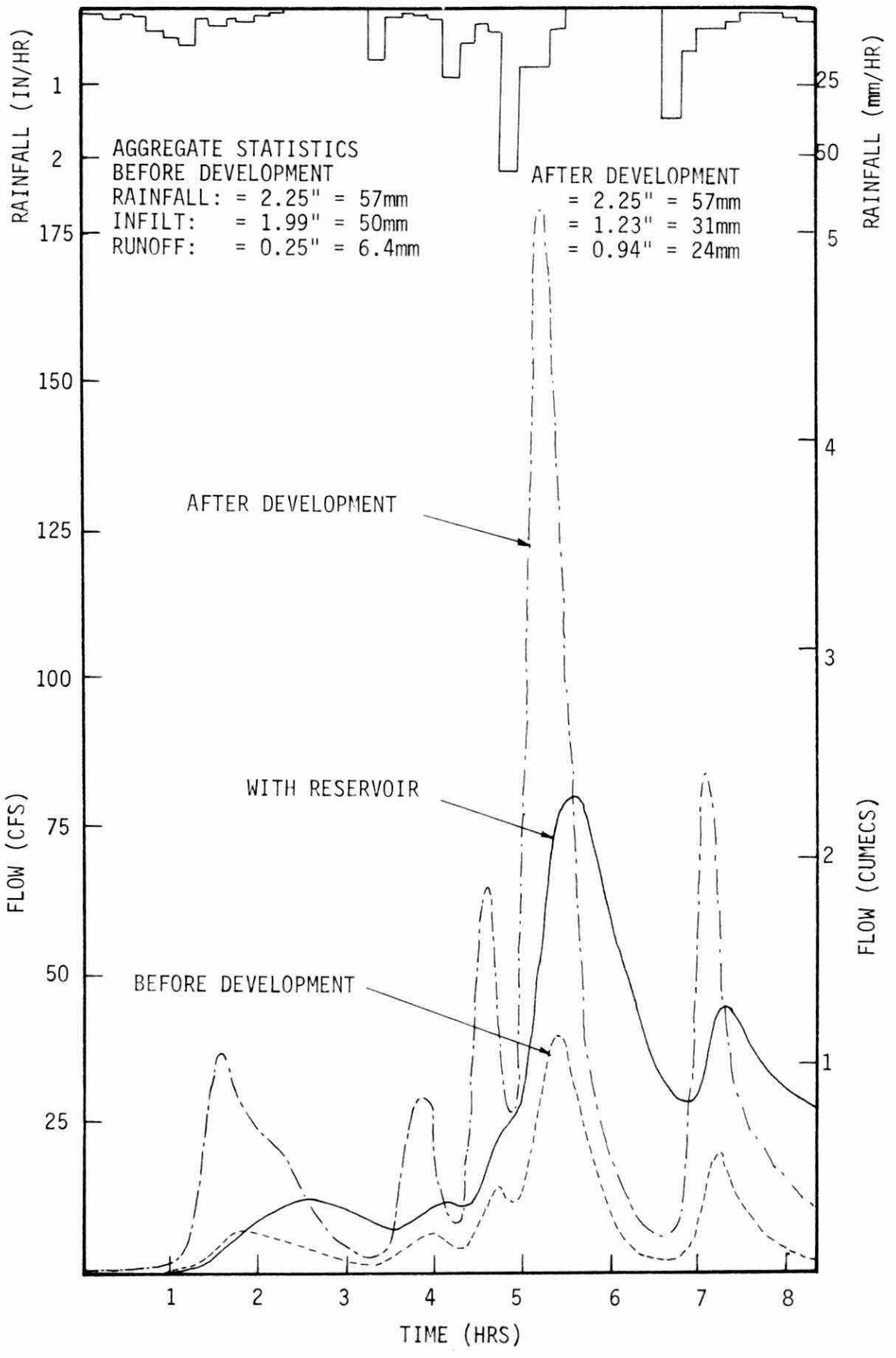


FIGURE 12. SWMM SIMULATION HYDROGRAPHS (STORM OF MAY 16, 1974)

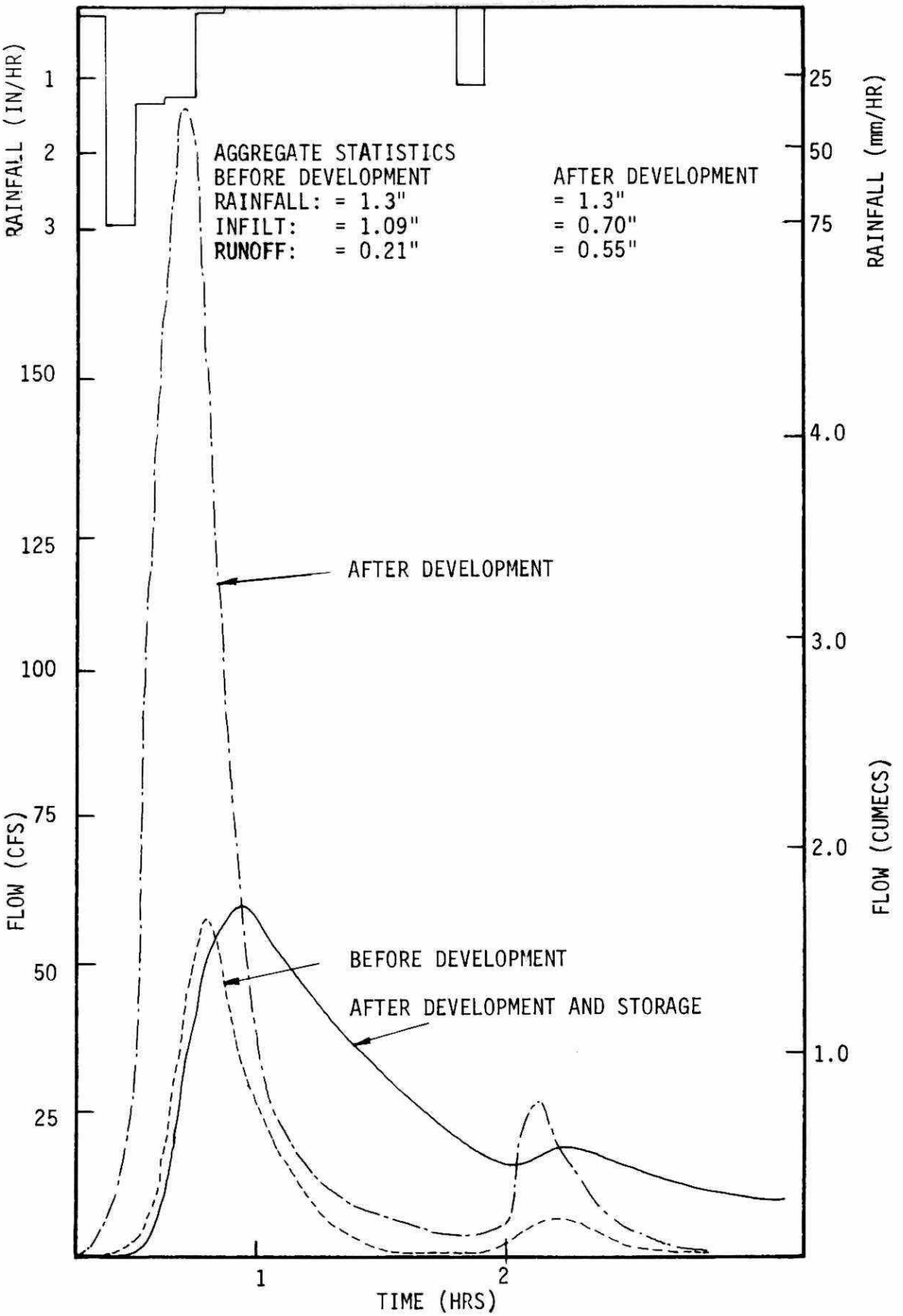


FIGURE 13. SWMM SIMULATION HYDROGRAPHS (STORM OF JULY 3, 1974)

This meant that either the results for urbanized conditions were too large or that the results for undeveloped conditions were too small. It was concluded that the SWMM predictions for undeveloped conditions were too low for two reasons:

a) SWMM is designed for urban runoff computations and has not been widely tested on undeveloped catchments.

b) The STORM prediction of runoff using a relatively low coefficient of 0.25 was between 50% and 100% greater than the SWMM result.

6.3 Storage Effects

Net evaporation from the Meadowvale dam (10"/year) represents approximately 0.4" of runoff from the catchment or a reduction of 5% in the annual yield of 7.08" (corrected average annual runoff predicted by STORM). Therefore, the storage system at Meadowvale will have little effect on runoff yield. The influence on peak flow is, however, much greater. Figures 11-13 show how, for specific events, the incoming hydrograph is attenuated and discharged over a much longer period.

At the outset of this work, it was hoped that the Meadowvale system would give a reduction of peak flow to pre-urbanized levels for storms up to some nominal return period (10 years). Apparently, this level of reduction is only obtained for relatively small storms, e.g., 4th of March. Considering the physical size of the dam, with an area of ± 10 acres and available storage (between the Morning Glory and the Emergency Spillway levels) equivalent to 1.5" of runoff, there is obviously scope for improvement of the discharge characteristics.

The basic reason for the poor performance (in terms of peak reduction) is the eight-foot radius drop-inlet spillway. Designed using the rational method, to discharge "Hurricane Hazel" with a maximum head on the crest of 2.1', the spillway does not throttle low flows and prevents efficient use of storage. For the May 16th storm, for instance, the predicted maximum level reached was only 7". While there is certainly a need to safely pass the possible maximum flood, it is noted that an emergency spillway, provided at a level three feet above the drop-inlet spillway, is adequate for this purpose.

To investigate possible improvements in the spillway design, three alternatives were examined: drop-inlet spillways with radii of two feet and four feet, and a controlled outlet (e.g., pumping) of 8 cfs. For the three large storms of 1974, the discharge hydrographs are shown in Figures 14-16. In addition, the largest storm for each year from 1961-1974, inclusive, was studied using the STORM predictions of flow hydrographs. The flows were routed and the maximum discharge and water level reached for each storm was calculated. The computation was not performed for the constant discharge cases. These results are examined in Table 9.

The following observations are relevant:

1) Both models first calculate the pollutant mass washed off during a time interval and this mass is then divided by the runoff volume to obtain concentration of the pollutant. In many cases, concentration of the pollutant is proportional to the flow rate, but may also decrease with the increasing flow rate.

2) The use of a spillway as a flow restriction results in a considerable reduction in peak flows for a relatively small change in storage utilization.

3) For a controlled constant discharge of 8 cfs (which incidently would allow 3 feet of drawdown in 45 hours), the maximum head reached for the May 16th storm was 13", i.e., by increasing the storage utilization by 6", the peak flow is reduced from 65 to 8 cfs.

4) The system as designed at Meadowvale, if subjected to the rainfall history for the period 1961-1974, would record a maximum water level above the spillway of one foot, corresponding to a peak discharge of 186 cfs. With a four-foot radius drop-inlet spillway, these values change to 1.3 feet and 140 cfs, respectively.

5) Generally, the relative reduction in peak flows due to the dam (measured as ratio of peak flow without the dam to peak

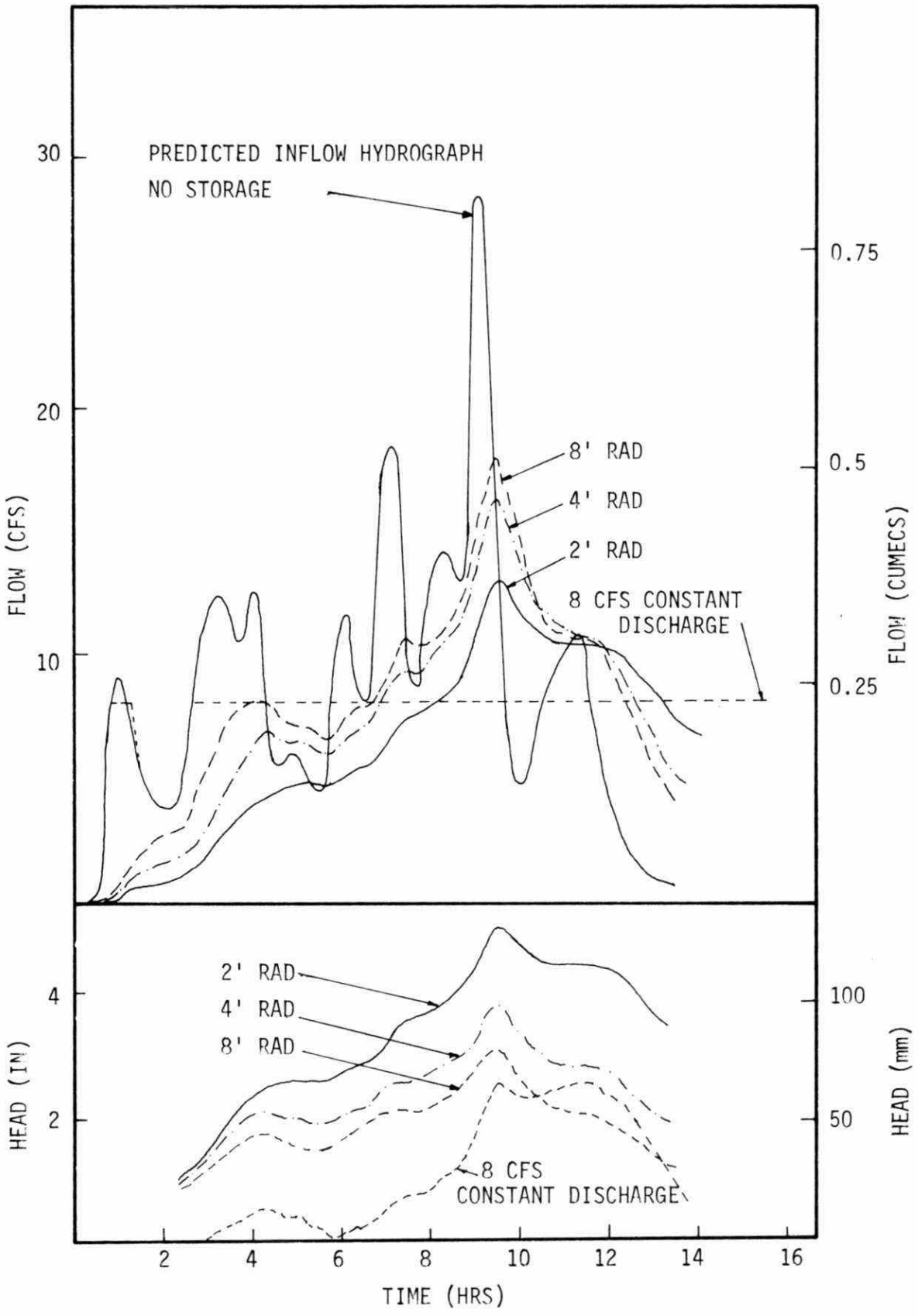


FIGURE 14. EFFECT OF DIFFERENT OUTLET CONDITIONS ON OUTFLOW CHARACTERISTICS AND STORAGE USE (STORM OF MARCH 4, 1974)

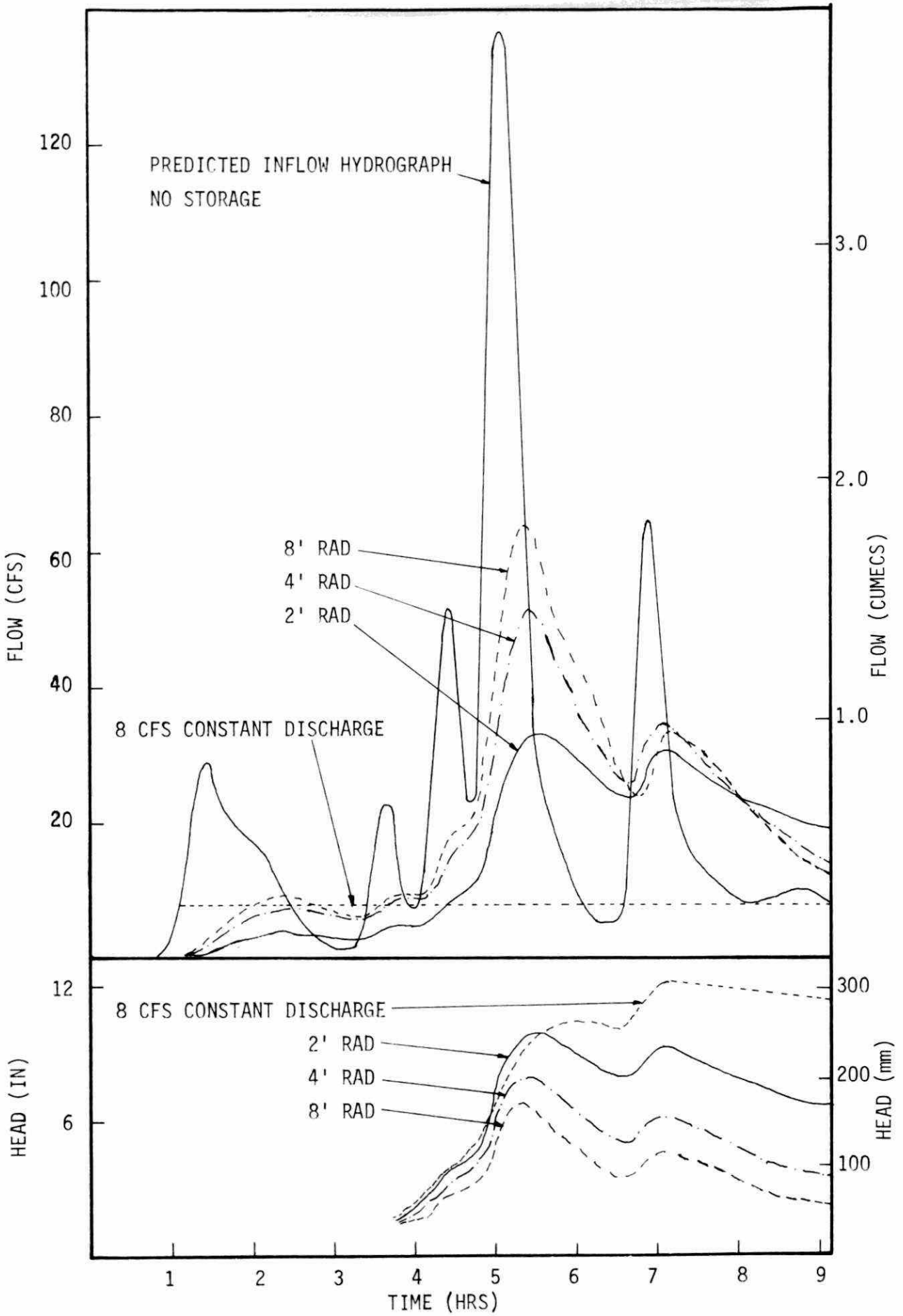


FIGURE 15. EFFECT OF DIFFERENT OUTLET CONDITIONS ON OUTFLOW CHARACTERISTICS AND STORAGE USE (STORM OF MAY 16, 1974)

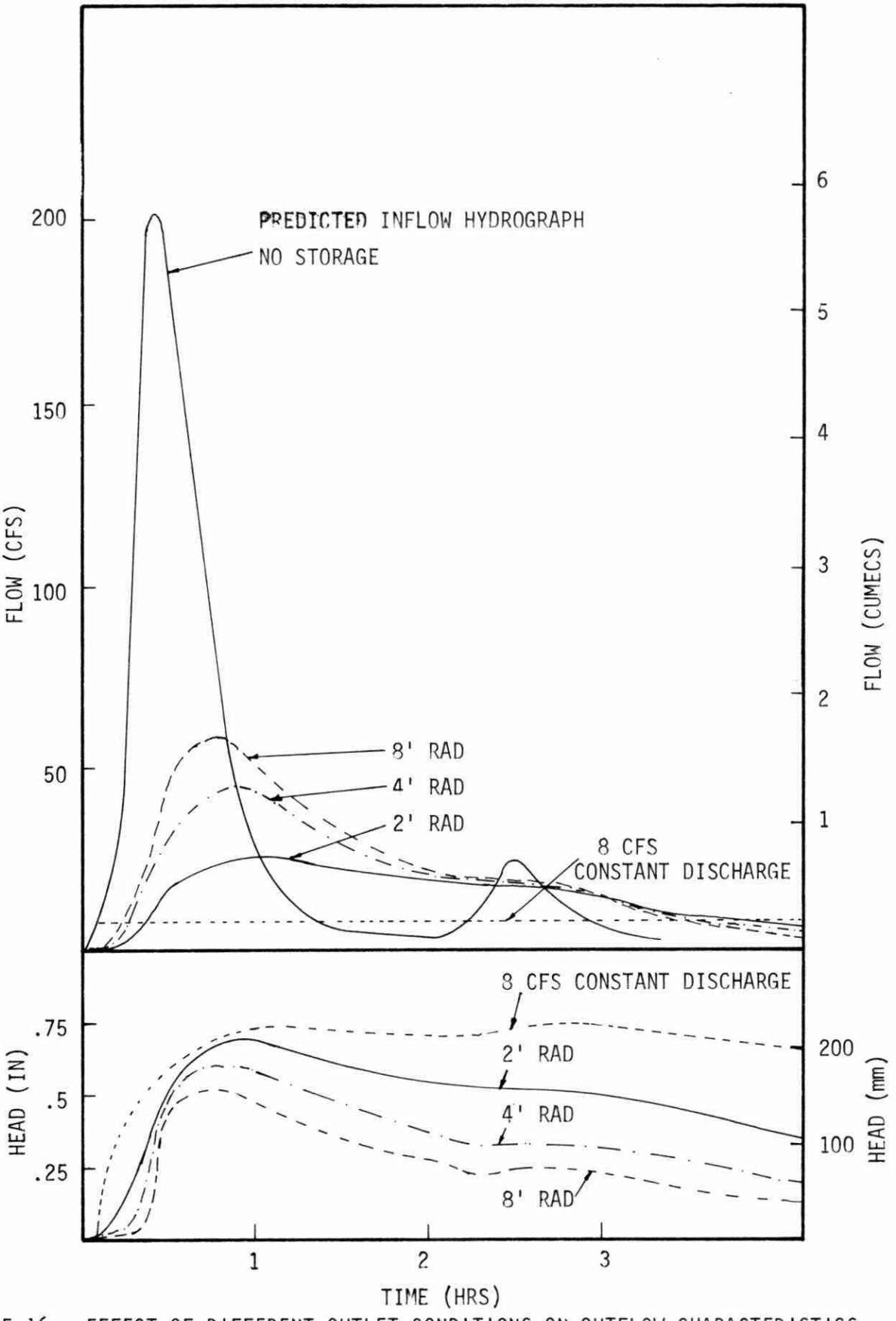


FIGURE 16. EFFECT OF DIFFERENT OUTLET CONDITIONS ON OUTFLOW CHARACTERISTICS AND STORAGE USE (STORM OF JULY 3, 1974)

TABLE 9. ANALYSIS OF THE EFFECTS OF VARIOUS DISCHARGE OPTIONS ON OUTFLOW CHARACTERISTICS

STORM	RANK	PEAK[a] BEFORE URB P1(CFS)	PEAK[a] AFTER URB P2(CFS)	P2/P1	STORAGE EFFECTS											
					8' RAD SPILLWAY				4' RAD SPILLWAY				2' RAD SPILLWAY			
					PEAK P3(CFS)	P3/P2	P3[c]/P1	MAX H"	PEAK P3(CFS)	P3/P2	P3[c]/P1	MAX H"	PEAK P3(CFS)	P3/P2	P3[c]/P1	MAX H"
31/7/70	1	107	209	1.95	185	.89	1.74	12	139	.66	1.28	16	64	.31	.60	21
22/8/68	2	95	186	1.95	165	.89	1.74	11	125	.67	1.30	15	63	.33	.64	19
24/7/69	3	62	122	1.96	109	.89	1.74	8	85	.70	1.37	11	51	.42	.82	14
16/5/74	4	50	97	1.94	86	.89	1.74	7	68	.70	1.35	9½	45	.46	.90	12½
12/7/62[b]	5	44	89	2.02	63	.71	1.43	6	41	.46	0.93	7	24	.27	.54	8
2/4/67	6	41	80	1.95	60	.75	1.46	5½	41	.51	0.99	7	24	.30	.58	8
2/8/65	7	37	72	1.95	54	.75	1.46	5	37	.51	0.99	6½	22	.31	.60	8
3/9/66	8	36	70	1.94	54	.77	1.50	5	37	.53	1.03	6½	22	.31	.60	7½
28/8/64	9	35	69	1.97	51	.74	1.46	5	35	.51	1.00	6	22	.32	.63	7½
26/7/71[b]	10	34	73	2.14	50	.68	1.45	5	32	.44	0.94	5½	18	.25	.54	6½
20/7/63	11	33	64	1.94	42	.66	1.28	4	27	.42	0.81	5	18	.28	.54	6½
2/10/73	12	30	58	1.93	42	.72	1.39	4½	28	.48	0.93	5½	16	.28	.54	6
24/9/61[b]	13	26	56	2.15	36	.64	1.38	4	22	.39	0.84	4½	12	.21	.45	5
27/6/72[b]	14	16	49	3.06	29	.59	1.80	3½	18	.37	1.13	4	10	.20	.61	4½

NOTES:

a THESE INFLOW HYDROGRAPHS ARE BASED ON PREDICTIONS BY STORM AND ARE LOW.

b THESE STORMS EXHIBIT LARGE P2/P1 RATIOS BECAUSE PEAK FLOWS OCCURRED BEFORE DEPRESSION STORAGE WAS FULL.

c THIS RATIO IS INDICATIVE OF THE OVERALL EFFECTS OF URBANIZATION AND STORAGE ON STORM PEAKS.

flow with the dam) is greater for the smaller, more frequent storms.

6) For the design of storage facilities such as the Meadowvale dam, consideration should be given to the use of two spillways, a lower spillway designed to restrict flows to pre-urbanized levels for a nominal return period, and an upper spillway to function during low frequency (emergency) floods. For large dams this procedure is obviously uneconomic, requiring expensive flood servitudes and a higher dam, but for smaller systems these are not usually problems. For Meadowvale, a four-foot radius drop-inlet spillway in conjunction with an emergency spillway gives considerable improvement in flood characteristics.

7) The results in Table 9 are based on STORM predictions which, as has been discussed, yielded overestimates of total runoff and underestimates of peak flows. Although these factors tend to cancel each other, the values given here are probably correct only to within 20% error.

7. POLLUTION SIMULATION

7.1 General

As previously discussed, the available storm water simulation models are not yet developed enough to give accurate predictions of the quality of storm water even if calibration data are available. Given the complexity of the processes involved and the difficulty of obtaining useful data, the full development of such a predictive capability in the near future is unlikely and the present simplistic models will continue to be an important tool for the evaluation of storm water pollution problems.

Modelling of runoff quality for undeveloped catchments using SWMM is extremely difficult as an arbitrary gutter length (pollutant source) has to be chosen (in this case a constant 300 feet for each sub-catchment). Presented in Figures 17 and 18 are predicted pollutographs using SWMM for both urbanized and undeveloped conditions (units are given both as concentration (mg/l) and mass emissions (lb/min); generally, for storm water studies, mass flow units which include the effects of a highly variable flow are preferred). The mass pollutographs for undeveloped conditions have been adjusted up by a factor of two to account for the suspected discrepancy in the runoff. Erosion was considered only in the prediction for undeveloped conditions as it did not seem important for a developed catchment.

The following observations were made:

1) A severe degradation in the quality of the runoff due to urbanization is predicted. BOD, N and PO_4 yields will increase approximately thirty times while SS yields will increase up to fifteen times. The difference between the BOD and SS increases is due to erosion, which was considered for the undeveloped condition. Basically, the conclusion is that developed conditions without erosion considered produce more SS than undeveloped conditions with erosion considered.

2) A comparison with typical measured pollutant concentrations in storm water (Table 10), indicates that for developed

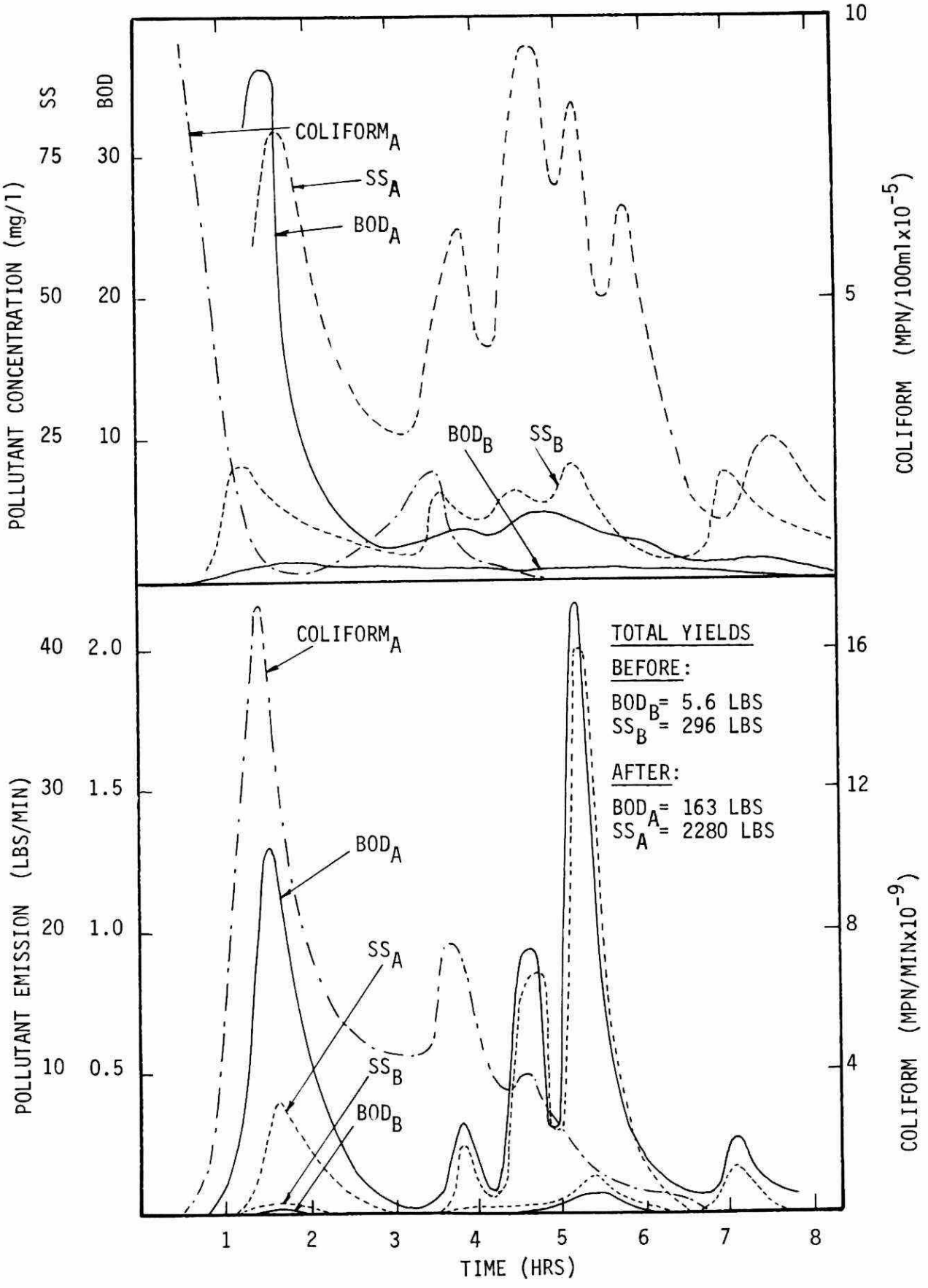


FIGURE 17. SWMM POLLUTOGRAPHS FOR THE STORM OF MAY 16, 1974, BEFORE AND AFTER DEVELOPMENT. B includes erosion; A does not include erosion.

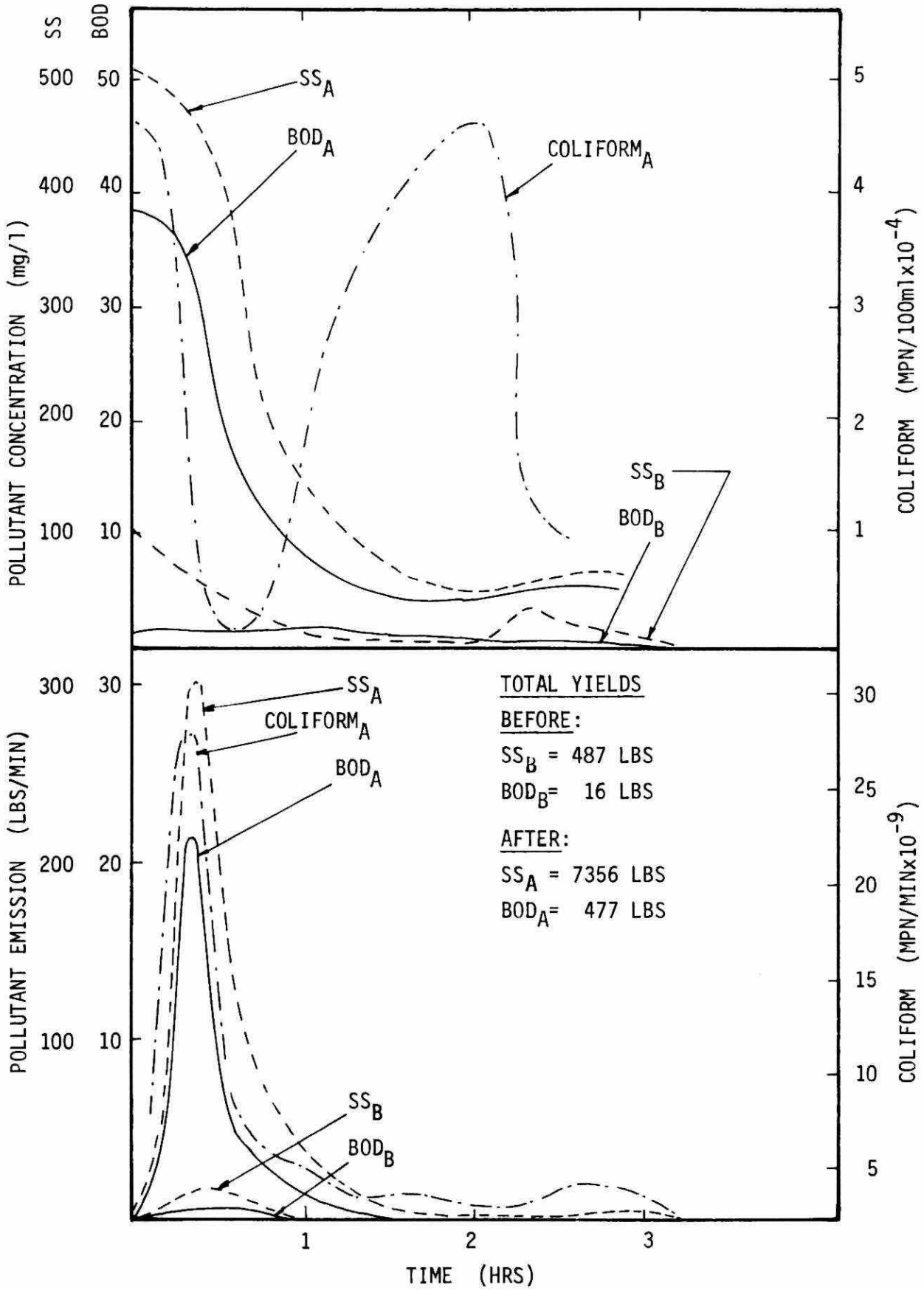


FIGURE 18. SWMM POLLUTOGRAPHS FOR THE STORM OF JULY 3, 1974 BEFORE AND AFTER DEVELOPMENT. B includes erosion; A does not include erosion.

TABLE 10. COMPARISON OF THE QUALITY OF STORM SEWER DISCHARGES.
(DATA ABSTRACTED FROM ENVIRONMENTAL PROTECTION AGENCY, 1974)

CITY	BOD mg/l AVE	BOD mg/l RANGE	SS mg/l AVE	SS mg/l RANGE	COLIFORMS* MPN/100 ml AVE	COLIFORMS* MPN/100 ml RANGE	TOT N mg/l as N AVE	TOT P mg/l as P AVE
ANN ARBOR MICHIGAN 1965	28	11-62	2080	650-11900	-	-	3.5	1.7
DES MOINES IOWA 1969	36	12-100	505	95-1050	-	-	2.2	0.87
DORHAM N. CAROLINA 1968	31	2-232	-	-	3×10^5	3×10^3- 2×10^6	-	-
SACREMENTO CALIFORNIA 1968-69	106	24-283	71	3-211	8×10^5	2×10^4- 1×10^7	-	-
TULSA OKLAHOMA 1968-69	11	1-39	247	84-2052	6×10^5	1×10^5- 3×10^6	0.3 - 1.5**	0.2 - 1.2**
WASHINGTON D.C. 1969	19	3-90	1697	130-11280	1×10^5	1×10^3- 5×10^8	2.1	0.4
WINDSOR ONTARIO 1972	12	2-52	305	2-4122	2×10^6	1×10^3- 2×10^7	1.6	0.98**
MEADOWVALE PREDICTED (SWMM) DEVELOPED	-	1-50	-	5-500	-	1×10^3- 1×10^6	-	-

* only fecal
** nitrogen as organic (kjeldahl), phosphorus as orthophosphate

conditions the predictions are of the correct order of magnitude. The pollutographs for undeveloped conditions appear, however, to be too low, possibly due to an incorrect choice of gutter length.

3) The coliform predictions exhibited computational instability (Figure 18). This may have been due to insufficient machine storage for the very large number being modelled.

4) The suspended solids prediction for undeveloped conditions was not sensitive to the washoff of dust and dirt (i.e. no first flush effect) because erosion was the major component of the suspended solids.

For flooding considerations, the design event is invariably a low-frequency storm (e.g., a ten-year storm for urban drainage design), but for quality considerations the average monthly storm may be more important in terms of the mass of pollutants contributed than the ten-year storm. Therefore, for the management of storm water quality, the concern seems to be with aggregate pollutional loadings and not with the effects of specific events.

7.2 Pollutant Yield Predictions

The University of Toronto version of STORM (subroutine MIKE) was used to predict annual pollutant yields from the Meadowvale catchment to the Credit River for three conditions, i.e., an undeveloped catchment, an urbanized catchment, and an urbanized catchment with runoff routed through a settling basin-reservoir system. These predictions are summarized in Table 11. If the settling basin-dam system for Meadowvale behaves as assumed, the yields of SS, SETL S and BOD will be reduced below levels existing before urbanization. The system does not have much effect on soluble conservative pollutants; nitrogen and orthophospate are reduced only by 25% and 16%, respectively. However, it is not expected that either of the two models studied will give good estimates for predevelopment conditions.

Shown in Table 12 are pollutant yields reported by other researchers; the STORM predictions are seen to be of the correct magnitude. Comparing the average pollutant load discharge from Meadowvale with that

TABLE 11. PREDICTED POLLUTANT YIELDS FOR MEADOWVALE USING STORM

Average Annual Statistics for 14 Years of Record

For the Period Beginning April 9, 1961, and Ending December 12, 1974

1. Before Urbanization	SUSPS	SETL S	BOD	N	PO_4
Total Pounds Washoff From Watershed	8131	699	1055	232	87
Total Pounds Overflow to Receiving Water	8128	706	1060	247	106
Concentration of Pollutants in Overflow to Receiving Water (mg/l)	36.16	3.14	4.72	1.10	0.47
Fraction of Total Washoff Overflowing to Receiving Water	1.00	1.01	1.00	1.06	1.22
Fraction of Total Washoff Initially Overflowing to Receiving Water	0.68	0.68	0.68	0.72	0.82

2. After Urbanization	SUSPS	SETL S	BOD	N	PO_4
Total Pounds Washoff from Watershed	41409	3165	6239	2284	211
Total Pounds Overflow to Receiving Water	41404	3169	6241	2289	231
Concentration of Pollutants in Overflow to Receiving Water (mg/l)	84.61	6.48	12.75	4.68	0.47
Fraction of Total Washoff Overflowing to Receiving Water	1.00	1.00	1.00	1.00	1.09
Fraction of Total Washoff Initially Overflowing to Receiving Water	0.70	0.68	0.73	0.71	0.77

Total Pollutant Yields Overflowing from Dam (lb)	SUSPS	SETL S	BOD	N	PO_4
	2658.9	67.9	299.8	1678.7	188.1

Total Pollutant Yields Overflowing from Settling Basin (lb)	SUSPS	SETL S	BOD	N	PO_4
	7122.7	720.6	3616.7	1718.7	193.0

TABLE 12. COMPARISON OF REPORTED POLLUTANT YIELDS FOR DIFFERENT CITIES WITH PREDICTED YIELDS FOR MEADOWVALE

Location	LOADINGS IN POUNDS/ACRE/YEAR* (kg/ha/yr) BOD	SS	Total N	Total P
OXHEY ENGLAND	4 (4.5)	103 (115)	- -	- -
CINCINNATI OHIO	33 (37)	730 (818)	8.9 (9.9)	2.5 (2.8)
ANN ARBOR MICHIGAN	31 (35)	1010 (1132)	1.9 (2.1)	2.8 (3.1)
DURHAM N. CAROLINA	84 (94)	- -	- -	3.4 (3.8)
WINDSOR ONTARIO	22 (25)	440 (493)	2.85 (3.19)	7.96** (8.9)
MEADOWVALE PREDICTION. DEVELOPED CONDITIONS USING STORM	23 (26)	154 (172)	8.4 (9.4)	0.78** (0.87)

* These data abstracted from references

** Orthophosphate only

from a typical secondary treatment plant serving the same population, the following resutls were obtained:

- Estimated population in Meadowvale catchment at 20/acre = 4800.
- At BOD equivalent = 0.17 lb/person/day, BOD load = 300,000 lb/year.
- At SS equivalent = 0.2 lb/person/day, SS load = 350,000 lb/year.
- Assuming a 90% treatment efficiency, BOD yield = 30,000 lb/year, compared to 5600 lb from storm water, and SS yield = 35,000 lb/year compared to 37,000 lb from storm water.

In terms of BOD, Meadowvale storm water is an insignificant nonpoint pollutant source; however, yields of suspended solids and nutrients can clearly not be ignored. Considering the quality of the Credit River (data for the years 1965-71 are given in Table 13), it is apparent that continued urbanization of the basin, with the associated increases in pollutant inputs (particularly nutrients and suspended solids), will damage the river and reduce its worth. The above analysis has ignored contaminants such as chlorides, asbestos, heavy metals (predominantly lead) and PCB's, which are known to occur in urban storm water.

Pollutant yields for 1974 (for urbanized conditions) were also calculated using the SWMM predictions and the regression equations of Colston and Tafuri (1975). This information is given in Table 14. The predictions using the three methods are conspicuously different and some explanation is required if the previous discussion is to have any credibility.

Firstly, the regression equations developed by Colston and Tafuri are valid for a specific catchment in North Carolina. Although this catchment has similar land uses to Meadowvale, the drainage system consists of ditches instead of pipes and the extrapolation of the regression equations to Meadowvale or any other area is not justified. The results do, however, illustrate the range and variability of storm water pollution.

Secondly, comparing the SWMM and STORM predictions for 1974, it seems that BOD and SS yields are markedly different (SWMM BOD = 9,400 lb and STORM BOD = 5,600 lb; SWMM SS = 117,000 lb and STORM SS = 37,300 lb). These values have been adjusted for difference in runoff (i.e., SWMM yield increased by 1.4 to include missing rainfall and STORM yields decreased by 1.1 to account for the suspected overestimate of total runoff).

TABLE 13. WATER QUALITY DATA FOR CREDIT RIVER. Taken at Station C-4.9 (Highway No. 5), from Ontario Water Resources Commission "Water Quality Data"

DATE	BOD_5 mg/l	SS mg/l	TOT N mg/l as N	TOT P mg/l as P
30/06/65	1.7	17	0.66	0.60
14/07/65	1.5	6	0.72	0.50
17/08/65	1.7	13	0.47	0.60
31/08/65	1.6	5	0.27	0.70
6/06/66	3.6	15	1.28	0.84
6/07/66	3.2	6	0.43	1.60
5/10/66	1.0	3	0.66	0.20
18/10/66	2.4	9	1.05	0.20
13/06/67	2.7	25	1.63	0.07
27/06/67	3.4	64	1.70	0.18
31/07/67	0.9	4	0.67	0.16
15/08/67	1.3	9	0.71	0.26
12/06/70	5.0	15	1.22	0.24
30/06/70	1.4	10	0.97	0.22
16/07/70	2.0	50	1.57	0.24
6/08/70	1.0	5	1.53	0.24
10/09/70	1.8	15	2.20	0.39
27/05/71	5.5	50	1.47	0.16
29/06/71	2.0	15	2.09	0.24
14/07/71	1.2	45	1.10	0.20
12/08/71	3.0	30	0.99	0.16
8/09/71	1.6	10	1.07	0.21

TABLE 14. COMPARISON OF PREDICTED YIELDS USING SWMM, STORM AND REGRESSION EQUATIONS (Assumes Meadowvale Fully Urbanized)

POLLUTANT	POLLUTANT YIELD LBS (Kg)		
	SWMM[1] PREDICTION	STORM[2] PREDICTION	REGRESSION[3] EQUATIONS
BOD	9400 (4270)	5600 (2540)	-
SS	117000 (53153)	37300 (16950)	354000 (160820)
TOT N AS N	-	1500 (680)	170[4] (77)
TOT P AS PO_4	-	142 (65)	480 (218)

1 - SWMM PREDICTIONS CORRECTED FOR MISSING RAINFALL

2 - STORM PREDICTIONS ADJUSTED TO ACCOUNT FOR SUSPECTED OVERESTIMATE OF RUNOFF

3 - REGRESSION EQUATIONS OF COLSTON AND TAFURI (1975)

4 - ONLY KJELDAHL

This is a strange result since SWMM and STORM use similar algorithms for modelling runoff quality. The reason for the difference is almost certainly that the "number of dry days" parameter assumed in each of the SWMM simulations was too high, giving a conservatively large estimate of pollutant buildup.

The wash-off of pollutants is also affected by the rate of runoff as illustrated by the following numerical example.

For suspended solids prediction, both models use the equation:

$$P_{OFF} = A \times P_{ON} \times (1 - e^{-KRT})$$

where: A = availability factor = $(0.057 + 1.4R^{1.1})$,

P_{ON} = suspended solids on catchment (assume = 10 lb),

P_{OFF} = suspended solids washed-off (the yield),

K = decay coefficient = 4.6,

R = runoff (in/hr),

T = time (hours).

Assuming a buildup of 10 lb of SS on the catchment and an extremely simple runoff pattern of 0.5 in/hr for 30 minutes, one obtains:

For SWMM, $R = 0.5$ in/hr $\quad T = 0.5$ hr

$$SS_{OFF} = (0.057 + 1.4 \times 0.5^{1.1}) \times 10 \times (1 - e^{-4.6 \times 0.5 \times 0.5})$$
$$= 4.8 \text{ lb.}$$

For STORM, $R = 0.25$ in/hr $\quad T = 1$ hr

$$SS_{OFF} = (0.057 + 1.4 \times 0.25^{1.1}) \times 10 \times (1 - e^{-4.6 \times 0.25 \times 1.0})$$
$$= 2.5 \text{ lb.}$$

While for BOD predictions, the models use the equation:

$$P_{OFF} = P_{ON} (1 - e^{-KRT}) + 0.1 \times SS_{OFF}$$

where: P_{ON} = BOD on catchment (assume 0.5 lb), and

P_{OFF} = BOD washed-off (the yield),

substituting applicable values into the BOD equation gives:

For SWMM, $BOD_{OFF} = 0.5(1 - e^{-4.6 \times 0.5 \times 0.5}) + 0.1 \times 4.8 = 0.82$

For STORM, $BOD_{OFF} = 0.5(1 - e^{-4.6 \times 0.25 \times 1.0}) + 0.1 \times 2.5 = 0.59.$

Thus, it is seen that STORM underestimates suspended solids yields because it underestimates peak flows. Soluble pollutants such as BOD and N are not as sensitive to the runoff rate. The STORM results discussed previously are acceptable as first-order estimates and the comparative analysis is relevent.

7.3 Meadowvale Reservoir Water Quality

The success and further application of the scheme at Meadowvale will largely depend on the quality of the reservoir water. If continual problems of odours, aquatic weed growth, algae blooms, etc., are experienced, the developer will not repeat this design strategy. Two factors determine the quality of the water, i.e. the characteristics of the catchment and the performance of the settling basin.

The system was simulated using the University of Toronto version of STORM. The settling basin has a predicted efficiency (Table 15), in terms of suspended solids removal, greater than 85% for 96% of the time. This very high efficiency is to be expected since with an area of 39,000 sq ft overflow rates are very low. The maximum flow rate in the 14-year period simulated was only 209 cfs (3410 U.S. gal/ft^2/d). The basin was designed using Stokes' equation for the settling velocity, "to settle out all particles larger than 0.07 mm (fine sand) during a discharge of 407 cfs" (Project Planning Associates, Ltd., 1975).

Pollutant inputs to the reservoir were computed using equations described before, and the average annual statistics have been listed in Table 11. The model does a continuous simulation of the quality of the dam water and provides a frequency analysis of the concentration of several pollutants for each month. These analyses for the months of June, July and August are shown in Table 16. The following observations can be made:

1) Concentrations of SS, SETL S and BOD are low. This reflects the assumptions of the model, i.e., a decay of pollutants to specified minimum values between storms. It is possible that a resuspension of solids could occur during turbulent conditions, while a higher BOD may be generated by the ecosystem.

TABLE 15. EFFICIENCY REPORT FOR SETTLING BASIN (Based on Hypothetical Performance Curve)

EFFICIENCY % SS REMOVAL	CORRESPONDING OVERFLOW RATE (U.S. Gal/Ft^2/D)	(m/D)	PERCENT OF TIME L.T.
5	3315	1010	0.00
10	2710	826	0.00
15	2350	716	0.00
20	2096	669	0.05
25	1920	585	0.11
30	1745	531	0.11
35	1600	487	0.16
40	1490	454	0.21
45	1385	422	0.21
50	1298	395	0.24
55	1210	368	0.29
60	1131	344	0.34
65	1061	323	0.58
70	1000	304	0.71
75	860	262	0.92
80	730	225	1.77
85	500	152	3.90
90	0	0	100.00

TOTAL NUMBER OF HOURS SIMULATED = 122554

HOURS OF STILLING BASIN USEAGE = 3796

TOTAL VOLUME OF SOLIDS REMOVED = 5997 Ft^3 = 170 m^3

TABLE 16. MONTHLY FREQUENCY ANALYSIS OF POLLUTANT CONCENTRATIONS IN RESERVOIR, STORM PREDICTIONS

MONTH NO = 5

RESERVOIR QUALITY ANALYSIS

S.S.		SET.S		BOD.		NIT.		PO4.		D. O.	
CONC MG/L	% TIME LT.	CONC MG/L	% TIME LT.	CONC MG/L	% TIME LT.	CONC MG/L	% TIME LT.	CONC MG/L	% TIME LT.		
5.00	1.937	2.00	100.000	2.00	100.000	0.20	0.0	0.10	0.0	1.00	0.0
10.00	100.000	5.00	100.000	4.00	100.000	0.40	0.0	0.15	6.718	2.00	0.0
20.00	100.000	10.00	100.000	6.00	100.000	0.60	0.0	0.20	6.718	3.00	0.0
30.00	100.000	15.00	100.000	8.00	100.000	1.00	0.586	0.25	6.718	4.00	0.0
50.00	100.000	20.00	100.000	10.00	100.000	2.00	6.718	0.30	9.931	5.00	0.0
75.00	100.000	25.00	100.000	12.00	100.000	3.00	31.210	0.35	33.336	6.00	0.0
100.00	100.000	30.00	100.000	14.00	100.000	4.00	57.120	0.40	42.493	7.00	0.0
150.00	100.000	35.00	100.000	16.00	100.000	5.00	100.000	0.45	57.120	8.00	0.0
200.00	100.000	40.00	100.000	18.00	100.000	6.00	100.000	0.50	85.807	9.00	0.803
900.00	100.000	75.00	100.000	25.00	100.000	10.00	100.000	0.60	100.000	16.00	100.000

MONTH NO = 6

RESERVOIR QUALITY ANALYSIS

S.S.		SET.S		BOD.		NIT.		PO4.		D. O.	
CONC MG/L	% TIME LT.	CONC MG/L	% TIME LT.	CONC MG/L	% TIME LT.	CONC MG/L	% TIME LT.	CONC MG/L	% TIME LT.		
5.00	1.840	2.00	100.000	2.00	99.864	0.20	0.0	0.10	0.0	1.00	0.0
10.00	99.981	5.00	100.000	4.00	100.000	0.40	0.0	0.15	5.713	2.00	0.0
20.00	100.000	10.00	100.000	6.00	100.000	0.60	0.0	0.20	8.191	3.00	0.0
30.00	100.000	15.00	100.000	8.00	100.000	1.00	0.0	0.25	8.191	4.00	0.0
50.00	100.000	20.00	100.000	10.00	100.000	2.00	8.191	0.30	15.666	5.00	0.0
75.00	100.000	25.00	100.000	12.00	100.000	3.00	22.512	0.35	23.606	6.00	0.0
100.00	100.000	30.00	100.000	14.00	100.000	4.00	58.801	0.40	38.033	7.00	0.0
150.00	100.000	35.00	100.000	16.00	100.000	5.00	100.000	0.45	59.072	8.00	0.0
200.00	100.000	40.00	100.000	18.00	100.000	6.00	100.000	0.50	78.495	9.00	17.942
900.00	100.000	75.00	100.000	25.00	100.000	10.00	100.000	0.60	100.000	16.00	100.000

MONTH NO = 7

RESERVOIR QUALITY ANALYSIS

S.S.		SET.S		BOD.		NIT.		PO4.		D. O.	
CONC MG/L	% TIME LT.	CONC MG/L	% TIME LT.	CONC MG/L	% TIME LT.	CONC MG/L	% TIME LT.	CONC MG/L	% TIME LT.		
5.00	1.741	2.00	99.991	2.00	99.944	0.20	0.0	0.10	0.0	1.00	0.0
10.00	99.963	5.00	100.000	4.00	100.000	0.40	0.0	0.15	0.0	2.00	0.0
20.00	100.000	10.00	100.000	6.00	100.000	0.60	0.0	0.20	7.131	3.00	0.0
30.00	100.000	15.00	100.000	8.00	100.000	1.00	0.0	0.25	7.131	4.00	0.0
50.00	100.000	20.00	100.000	10.00	100.000	2.00	7.131	0.30	13.945	5.00	0.0
75.00	100.000	25.00	100.000	12.00	100.000	3.00	26.382	0.35	27.090	6.00	0.0
100.00	100.000	30.00	100.000	14.00	100.000	4.00	65.435	0.40	34.742	7.00	0.0
150.00	100.000	35.00	100.000	16.00	100.000	5.00	100.000	0.45	66.375	8.00	0.0
200.00	100.000	40.00	100.000	18.00	100.000	6.00	100.000	0.50	88.801	9.00	100.000
900.000	100.000	75.00	100.000	25.00	100.000	10.00	100.000	0.60	100.000	16.00	100.000

2) Concentrations of nutrients (assuming no sources or sinks) are significantly larger than the threshold values (0.3 mg/l and 0.01 mg/l for inorganic nitrogen, N, and inorganic phosphorus, P, respectively) reported by Sawyer (1952) for the occurrence of algae blooms. Even if some nutrients are removed (e.g., by the growth of aquatic plants or the formation of complex precipitates), conditions suitable for algae growth will likely prevail. There are various alternatives for algae removal; one which appears suited to Meadowvale is the use of dilution water (Rohlich, 1969). A flow of 1 cfs during the months of June, July and August would reduce the average phosphorus concentration from 0.42 mg/l to 0.16 mg/l. The fairly fast turnover of water (once per annum) and the shape of the reservoir (conducive to plug flow) will tend to wash algae out and the problem will not necessarily occur.

3) Dissolved oxygen levels are close to saturation. As outlined, the decay of vegetation or algae could place a demand on the oxygen resource, however, depletion below 3 to 4 mg/l is unlikely and the reservoir should provide an adequate fish habitat.

4) Should anaerobic conditions develop in the settling basin, there is potential for a shock loading on the reservoir.

7.4 Sediment Yield and Erosion

Urbanization generally leads to an increased sediment yield from a catchment and to accelerated erosion in the plain of the river or stream which receives the urban runoff. Most of the sediment yield is due to smaller storms. Glymph (1967) studied the records of 72 watersheds in the United States ranging in size from 100 to 100,000 acres and concluded that storms with a return period of less than one year contributed between 34 and 92 percent of the aggregate sediment yield. As discussed before, the Meadowvale system can be expected to remove about 90% of the incoming sediment and in addition will reduce peak flows, which are known to be the major factor in river bank erosion.

For urban areas the major cost of erosion is not the loss of soil, but rather the cost of removing silt and debris from estuaries, reservoirs, and stream beds (e.g., the sediment deposited by the Don River in the Keating Channel of Toronto Harbour necessitates annual dredging of some 100,000 cubic yards).

Construction activities during the transition from rural to urbanized conditions are a major source of sediment. Yields as high as 140,000 tons/square mile have been reported (Dawdy, 1967) for small construction sites. The SWMM model has the capability of modelling erosion using the Universal Soil Loss Equation. An attempt was made to determine the order of increase in sediment that could be expected in Meadowvale during the development of land to the west of Winston Churchill Boulevard. These results are given in Table 17 and indicate a four-fold increase in sediment yield (i.e., from 60 tons/year to 240 tons/year) during the construction phase. This corresponds to a yield of between 160 to 640 tons/square mile/year. Since this part of the catchment will not be developed until after the dam is complete, the "computer guesses" above could easily be verified by the Ministry of the Environment in their program to monitor Meadowvale. It is unfortunate that the Meadowvale dam was not built prior to the construction of all the houses, roads and storm water sewers. Ideally, if a siltation basin storage system is planned, it should be constructed first so that maximum benefits may be obtained.

TABLE 17. PREDICTED INCREASE IN SEDIMENT YIELD DUE TO CONSTRUCTION (SWMM)

STORM OF MARCH 4

TOTAL SUSPENDED SOLIDS (INCLUDING S.S. FROM EROSION) TRANSFERRED TO THE SEWER FROM INLET AREAS DURING 78 TIME

INLET NO.	EROSION AREA(ACRES)	FLOW LENGTH(FT)	SOIL TYPE(K)	CROPPING FACTOR	CONTROL FACTOR	EROSION S.S.(MG)	TOTAL S.S.(MG)
1	0.50	350.00	0.30	0.01	0.10	0.2222E+05	0.1155E+09
2	0.80	700.00	0.30	0.01	0.10	0.7950E+05	0.4166E+09
3	0.60	300.00	0.30	0.01	0.10	0.3230E+05	0.6534E+09
4	6.60	800.00	0.30	0.01	0.10	0.1011E+07	0.3024E+09
5	6.70	600.00	0.30	0.01	0.10	0.1529E+07	0.1746E+09
6	10.80	700.00	0.30	0.01	0.10	0.1972E+07	0.1142E+09
7	13.00	1000.00	0.30	1.00	0.70	0.3476E+10	0.3557E+10
8	25.00	600.00	0.30	1.00	0.70	0.1399E+10	0.1543E+10
9	13.00	700.00	0.30	1.00	0.70	0.9454E+09	0.9932E+09
10	25.00	1400.00	0.30	1.00	0.70	0.1934E+10	0.2026E+10
11	1.00	400.00	0.30	0.01	0.10	0.1518E+06	0.1240E+09

TOTAL EROSION CONTRIBUTION: 0.77602E+10 MG, 17093.0 LB

TOTAL SUS-S: 0.10019E+11 MG, 22069.1 LB

INCREASE DUE TO EROSION = 4.4

STORM OF MAY 16

TOTAL SUSPENDED SOLIDS (INCLUDING S.S. FROM EROSION) TRANSFERRED TO THE SEWER FROM INLET AREAS DURING 59 TIME

INLET NO.	EROSION AREA(ACRES)	FLOW LENGTH(FT)	SOIL TYPE(K)	CROPPING FACTOR	CONTROL FACTOR	EROSION S.S.(MG)	TOTAL S.S.(MG)
1	0.50	350.00	0.30	0.01	0.10	0.2938E+05	0.4425E+08
2	0.80	700.00	0.30	0.01	0.10	0.1051E+06	0.1487E+09
3	0.60	300.00	0.30	0.01	0.10	0.4271E+05	0.2161E+09
4	6.60	800.00	0.30	0.01	0.10	0.1337E+07	0.1695E+09
5	6.70	600.00	0.30	0.01	0.10	0.2022E+07	0.9992E+08
6	10.80	700.00	0.30	0.01	0.10	0.2608E+07	0.9309E+08
7	13.00	1000.00	0.30	1.00	0.70	0.4597E+10	0.4663E+10
8	25.00	600.00	0.30	1.00	0.70	0.1850E+10	0.1956E+10
9	13.00	700.00	0.30	1.00	0.70	0.1250E+10	0.1289E+10
10	25.00	1400.00	0.30	1.00	0.70	0.2558E+10	0.2626E+10
11	1.00	400.00	0.30	0.01	0.10	0.2008E+06	0.6963E+08

TOTAL EROSION CONTRIBUTION: 0.10262E+11 MG, 22603.2 LB

TOTAL SUS-S: 0.11374E+11 MG, 25053.3 LB

INCREASE DUE TO EROSION = 10

STORM OF JULY 3

TOTAL SUSPENDED SOLIDS (INCLUDING S.S. FROM EROSION) TRANSFERRED TO THE SEWER FROM INLET AREAS DURING 20 TIME

INLET NO.	EROSION AREA(ACRES)	FLOW LENGTH(FT)	SOIL TYPE(K)	CROPPING FACTOR	CONTROL FACTOR	EROSION S.S.(MG)	TOTAL S.S.(MG)
1	0.50	350.00	0.30	0.01	0.10	0.3174E+05	0.1301E+09
2	0.80	700.00	0.30	0.01	0.10	0.1136E+06	0.4408E+09
3	0.60	300.00	0.30	0.01	0.10	0.4614E+05	0.6395E+09
4	6.60	800.00	0.30	0.01	0.10	0.1445E+07	0.4979E+09
5	6.70	600.00	0.30	0.01	0.10	0.2185E+07	0.2912E+09
6	10.80	700.00	0.30	0.01	0.10	0.2818E+07	0.3088E+09
7	13.00	1000.00	0.30	1.00	0.70	0.4967E+10	0.5193E+10
8	25.00	600.00	0.30	1.00	0.70	0.1999E+10	0.2323E+10
9	13.00	700.00	0.30	1.00	0.70	0.1351E+10	0.1481E+10
10	25.00	1400.00	0.30	1.00	0.70	0.2764E+10	0.2979E+10
11	1.00	400.00	0.30	0.01	0.10	0.2169E+06	0.2051E+09

TOTAL EROSION CONTRIBUTION: 0.11038E+11 MG, 24422.9 LB

TOTAL SUS-S: 0.14489E+11 MG, 31914.5 LB

INCREASE DUE TO EROSION = 4.5

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A P P E N D I X

SUBROUTINE "MIKE" -

PROGRAM SOURCE AND MODIFICATIONS TO STORM

```
      SUBROUTINE MIKE                                                   5500
      COMMON          IRAIN(200,24),JDATE(200),JDAY(200),               5501
     .                KRAIN(200,24),KDATE(200),KDAY(200)                5503
C                                                                       5504
      COMMON /REEL/ AGE,AGE2,AGE3,AGE4,AGE5,AGE6,AGE7,AGE8,             5505
     1              AMXOLD,C,CIAT,CIMP,CN,CPERV,DD1,DEP,DEPN,DEPRES,    5506
     2              DEPRN,DEPRS,DUR,E,EXPTE,EXPTN,HUND,OLD,PRCP,        5507
     3              PRCPN,RAINRT,RAINX,REFF,RFN,RFU,RTOCFS,RUN,         5508
     4              RUNOF,SACFT,SAGE,SAGE2,SAGE3,SAGE4,SAGE5,SAGE6,     5509
     5              SAGE7,SAGE8,SMG,SRUN,TAREA,TCFS,TMGD,URC,           5510
     6              XAGE,XAGE2,XAGE3,XAGE4,XAGE5,XAGE6,XAGE7,XAGE8,     5511
     7              XRUN,YRAIN,YRUN,ZEX                                 5512
C                                                                       5513
      COMMON /DIMN/ CAPR(20,20),CP(5),DD(5),DELTP(5,5),DELTPN(5),       5514
     1              EIMP(5),EFACTN(5,5),P(5,5),PN(5),POL(5),POLEX(5),   5515
     2              POLLRT(5),POLNRT(5),POLOVR(5),RECVN(12),            5516
     3              RECVRT(12),SSUMPO(5),STLEN(5),SUMPOL(5),            5517
     4              TPATER(20),XPOLEX(5),XPOLOV(5),XSUMPO(5)            5518
C                                                                       5519
      COMMON /ITGR/ CAP,CST,EX,EXCES,IA,IB,ICC,ID,IDATE,IEND,IL,IN,     5520
     A              IP,IPACK,IPRINT,IP1,IP2,IR,IRUN,ISTART,ISCH,IT,     5521
     B              J,JHR,JMX,KK,KMAX2,KMX,L,LAST,LDATE,                5522
     C              LEXT,LHUND,LI,LL,LOSS,LSDF,M,MASE,MASS,             5523
     D              MAXLIN,MISS,MO,MPAGE,MST,MXC,     MXSTOR,           5524
     E              MXTIM,NAM,NANTEC,NC,NCAP,NDAYRC,NDAY1,NDRY,         5525
     F              NHR,NINC,NMAX,NN,NNRAIN,NOEXTR,NORAIN,              5526
     G              NORUN,NORUNN,NOSTOR,NPAGE,NSUMR,RAIN,SDATE,         5527
     H              SDAY,SDUR,SEX,SEXCES,SHR,SMST,SMXSTO,               5528
     I              SNOSTO,SRAIN,STCAP,STNSTO,STOP,STOR,                5529
     J              STORD,STORG,STRAIN,STREAT,STSTO,TCAP,               5530
     K              TNSTOR,TOP,TRAIN,TREAT,TSTOR,XCST,XDUR,             5531
     L              XRAIN,XTNSTO,XTOP,XTRAIN,XTREAT,XTSTO               5532
C                                                                       5533
      COMMON /IDIM/ DSTOR(600),ICNAME(5),IPOLUT(20),LPAGE(5),           5534
     1              LSDIST(1000),LTDIST(1000),NAME(8),NAMEWS(4),        5535
     2              NCLEAN(5),ND(12),NTITLE(20),TRATE(20),YSUMPO(5)     5536
C                                                                       5537
      COMMON/UOFT/PVOL,ARP1,WTP2,RVOL,NHTS,HAJ(5),ARJ(5),QC1,S1,        5538
     U            WDIM,CONC(6),ROUT2(51),DONE,STORR(51),CFLOW(51),PREV, 5539
     V            SURE,SCONC(6,10),SIM(6,10,12),JPREV,LX,DD2(12),       5540
     W            TEMP(12),SEFF(10),MCOUNT,SOLIDS,HEFF                 5541
C          DECLARED INTEGER VARIABLES IN COMMON                         5542
      INTEGER   CAP,CST,DSTOR,DUR,EX,EXCES,RAIN,SDATE,SDAY,SDUR,        5543
     1          SEX,SEXCES,SHR,SMST,SMXSTO,SNOSTO,SRAIN,STCAP,          5544
     2          STNSTO,STOP,STOR,STORD,STORG,STRAIN,STREAT,STSTO,       5545
     3          TCAP,TNSTOR,TOP,TRAIN,TRATE,TREAT,TSTOP,                5546
     4          XCST,XDUR,XRAIN,XTNSTO,XTOP,XTRAIN,XTREAT,XTSTO,        5547
     5          YSUMPO,WTP2,DONE,SIM,SURE,HEFF,PREV,SEFF                5548
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      C                                                                         5548
            COMMON /SOIL/ AREA,AREAN,IER,IERDMX,IPRTS,IS,LINE,MEF,MI30,MXLG,    5549
           1              NONURB,NSTOR,REC,RMI,SMEC,XMH,                        5550
           2              DDL(6),EI(6),IERD(20),LNDUSE(6,2),PRCNT(6),WTQ(6)     5551
      C                                                                         5552
            INTEGER URE                                                         5553
            REAL OVFL,S202,S2,Q02,POLIN(6)                                      5554
      15000 FORMAT('1',132('*'),/,43X,'RESERVOIR REPORT FOR SELECTED EVENTS',/5555
           A,2X,'EVNT',7X,'DATE',7X,'HR',6X,'QIN',7X,'STORAGE',6X,'QOUT',6X,'S5556
           B.S.',5X,'SETL.S.',5X,'POD',7X,'TOT N',7X,'P',7X,'D.O.')             5557
      15100 FORMAT(11X,'YR MO DY',13X,'CFS',8X,'FT**3',7X,'CFS',7X,'MG/L',6X,'5558
           CMG/L',7X,'MG/L',6X,'MG/L',6X,'MG/L',6X,'MG/L',/,132('*'))           5559
      15200 FORMAT(I6,4X,3I3,5X,I2,5X,F5.1,5X,F9.0,5X,F5.1,3(5X,F5.0),3(5X,F5.5560
           D2))                                                                 5561
            MPRNT=0                                                             5562
            INSTOR=NSTOR+1                                                      5563
            IF(IPOLMX.EQ.0) GO TO 11115                                         5563100
            DO 11110 K=1,IPOLMX                                                 5564
            IF(IPOLUT(K).EQ.INSTOR.OR.IPOLUT(K).EQ.(INSTOR-1)) MPRNT=1          5565
      11110 CONTINUE                                                            5566
      11115 CONTINUE                                                            5566100
            IF(DONE.GT.1) GO TO 11160                                           5567
      C     FIRST ROUTING OF FLOWS                                              5568
      C     CALCULATE STAGE STORAGE DISCHARGE AT DIFFERENT HEADS                5569
            LX=0                                                                5570
            K=1                                                                 5571
            SOLIDS=0.                                                           5572
            HEFF=0                                                              5573
            PREV=0                                                              5574
            JPREV=24                                                            5575
            MCOUNT=0                                                            5576
            ROUT2(1)=0.                                                         5577
            STORR(1)=0.                                                         5578
            HEAD=0.                                                             5579
            OFLOW(1)=0.                                                         5580
            S2=0.                                                               5581
            Q01=0.                                                              5581100
            DO 11150 N=1,50                                                     5582
            HEAD=HEAD+0.1                                                       5583
            IF(HEAD.GT.(HAJ(NHTS))) GO TO 11160                                 5584
            IF(HEAD.GT.(HAJ(K+1))) K=K+1                                        5585
            STORR(N+1)=STORR(N)+0.1*((HEAD-HAJ(K)-0.05)*(ARJ(K+1)-ARJ(K))/(HAJ5586
           .(K+1)-HAJ(K))+ARJ(K))                                               5587
            IF(WTP2) 11120,11130,11140                                          5589
      C     OGEE SPILLWAY                                                       5590
      11120 OFLOW(N+1)=3.9*WDIM*HEAD**1.5*3600.                                 5591
            GO TO 11145                                                         5592
      C     MORNING GLORY                                                       5593
      11130 OFLOW(N+1)=(4.35-.19*HEAD/WDIM)*2.*3.1416*WDIM*HEAD**1.5*3600.      5594
            GO TO 11145                                                         5594
      C     CONTROLLED CONSTANT DISCHARGE                                       5595
      11140 OFLOW(N+1)=3600.*WDIM                                               5596
      11145 CONTINUE                                                            5597
            ROUT2(N+1)=OFLOW(N+1)+STORR(N+1)                                    5598
      11150 CONTINUE                                                            5599
      C     SUSPENDED SOLIDS CATEGORIES                                         5600
            SCONC(1,1)=5.                                                       5601
            SCONC(1,2)=10.                                                      5602
            SCONC(1,3)=20.                                                      5603
            SCONC(1,4)=30.                                                      5604
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                SCONC(1,5)=50.                                                  5605
                SCONC(1,6)=75.                                                  5606
                SCONC(1,7)=100.                                                 5607
                SCONC(1,8)=150.                                                 5608
                SCONC(1,9)=200.                                                 5609
                SCONC(1,10)=2000.                                               5610
1/6         C   SETTLEABLE SOLIDS CATEGORIES                                   5611
1               SCONC(2,1)=5.                                                   5612
2               SCONC(2,2)=10.                                                  5613
3               SCONC(2,3)=15.                                                  5614
4               SCONC(2,4)=20.                                                  5615
5               SCONC(2,5)=25.                                                  5616
6               SCONC(2,6)=30.                                                  5617
7               SCONC(2,7)=35.                                                  5618
8               SCONC(2,8)=40.                                                  5619
9               SCONC(2,9)=45.                                                  5620
10              SCONC(2,10)=75.                                                 5621
11          C   BOD CATEGORIES                                                 5622
12              SCONC(3,1)=5.                                                   5623
13              SCONC(3,2)=10.                                                  5624
14              SCONC(3,3)=15.                                                  5625
15              SCONC(3,4)=20.                                                  5626
16              SCONC(3,5)=25.                                                  5627
17              SCONC(3,6)=30.                                                  5628
18              SCONC(3,7)=40.                                                  5628
19              SCONC(3,8)=50.                                                  5629
20              SCONC(3,9)=75.                                                  5630
21              SCONC(3,10)=100.                                                5631
22          C   NITROGEN CATEGORIES                                            5633
23              SCONC(4,1)=0.2                                                  5634
24              SCONC(4,2)=0.4                                                  5635
25              SCONC(4,3)=0.6                                                  5636
26              SCONC(4,4)=0.8                                                  5637
27              SCONC(4,5)=1.0                                                  5638
28              SCONC(4,6)=2.0                                                  5639
29              SCONC(4,7)=4.0                                                  5640
30              SCONC(4,8)=8.0                                                  5641
31              SCONC(4,9)=10.                                                  5642
32              SCONC(4,10)=20.0                                                5643
33          C   PHOSPHOROUS CATEGORIES                                         5644
34              SCONC(5,1)=0.02                                                 5645
35              SCONC(5,2)=0.04                                                 5646
36              SCONC(5,3)=0.06                                                 5647
37              SCONC(5,4)=0.08                                                 5648
38              SCONC(5,5)=0.1                                                  5649
39              SCONC(5,6)=0.2                                                  5650
40              SCONC(5,7)=0.4                                                  5651
                SCONC(5,8)=0.8                                                  5652
                SCONC(5,9)=1.0                                                  5653
                SCONC(5,10)=5.0                                                 5654
            C   DISSOLVED OXYGEN CATEGORIES                                    5654
                SCONC(6,1)=1.                                                   5655
                SCONC(6,2)=2.                                                   5656
                SCONC(6,3)=3.                                                   5657
                SCONC(6,4)=4.                                                   5658
                SCONC(6,5)=5.                                                   5659
                SCONC(6,6)=6.                                                   5660
                SCONC(6,7)=7.                                                   5661
                SCONC(6,8)=8.                                                   5662
                SCONC(6,9)=9.                                                   5663
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                SCONC(6,10)=16.                                                  5664
                DO2(1)=14.6                                                      5665
                DO2(2)=14.6                                                      5666
                DO2(3)=14.6                                                      5667
                DO2(4)=12.4                                                      5668
                DO2(5)=10.8                                                      5669
1/6             DO2(6)=9.5                                                       5670
                DO2(7)=9.1                                                       5671
                DO2(8)=9.2                                                       5672
                DO2(9)=10.1                                                      5673
                DO2(11)=13.3                                                     5674
                DO2(12)=14.6                                                     5675
                OXDEF=DO2(MO)-CONC(6)                                            5676
      C         MEAN MONTHLY TEMP                                                5677
                TEMP(1)=4.                                                       5678
                TEMP(2)=4.                                                       5679
                TEMP(3)=6.3                                                      5680
                TEMP(4)=6.4                                                      5681
                TEMP(5)=12.                                                      5682
                TEMP(6)=18.2                                                     5683
                TEMP(7)=20.7                                                     5684
                TEMP(8)=20.0                                                     5685
                TEMP(9)=15.7                                                     5686
                TEMP(10)=9.8                                                     5687
                TEMP(11)=4.0                                                     5688
                TEMP(12)=4.0                                                     5689
      11160     CONTINUE                                                         5690
                LX=LX+1                                                          5691
      11180     CONTINUE                                                         5692
                HEFF=HEFF+1                                                      5693
                RUNOF=RUNOF*RTOCFS                                               5694
      C         ACCOUNT FOR TIME INTERVAL BETWEEN RUNOFFS                        5695
                IF(KDAY(LX).GT.PREV) GO TO 11190                                 5696
                URE=J-JPREV-1                                                    5697
                GO TO 11200                                                      5698
      11190     URE=23-JPREV+(KDAY(LX)-PREV-1)*24+J                              5699
      C         URE IS THE NO OF HOURS WITH NO RUNOFF                            5700
      11200     CONTINUE                                                         5701
                SURE=SURE+URE                                                    5702
                IF(URE.EQ.0) GO TO 11355                                         5703
                DO 11350 N=1,URE                                                 5704
                S1=S2                                                            5705
                S2O2=S1-QO1/2.                                                   5706
                IF(S2O2.GT.0.) GO TO 11210                                       5707
                S2=S1-RECVRT(MO)/288.*ARJ(1)                                     5708
                QO1=0.                                                           5709
                QO2=0.                                                           5710
      C         NO OUTFLOW RESERVOIR NOT FULL                                    5711
                GO TO 11305                                                      5712
      11210     CONTINUE                                                         5713
                DO 11250 K=1,50                                                  5714
                IF(ROUT2(K).GT.S2O2) GO TO 11260                                 5715
      11250     CONTINUE                                                         5716
      11260     S2=STORR(K)-RECVRT(MO)/288.*ARJ(1)                               5717
                QO2=OFLOW(K)                                                     5718
                QO1=QO2                                                          5719
      11300     CONTINUE                                                         5720
      11305     CONTINUE                                                         5721
      C         UPDATE WATER QUALITY USING DEFINED CATEGORIES FOR FREQ ANALYSIS  5722
      C         KZ1 IS DEOXYGENATION COEF  KZ2 IS REAERATION COEF                5723
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      KZ1=0.1*1.047**(TEMP(MO)-20.)                                          5724
      KZ2=0.075*1.024**(TEMP(MO)-20.)                                        5725
      FAC1=KZ1/(KZ1-KZ2)                                                     5726
      OXDEF=FAC1*CONC(3)*(10.**(-KZ1*N/24.)-10.**(-KZ2*N/24.))+OXDEF*10.5727
     .**(-KZ2*TDAYS)                                                         5728
      CONC(6)=DO2(MO)-OXDEF                                                  5729
1/6   CONC(3)=CONC(3)*10.**(KZ1*N/24.)                                       5730
      DO 11310 K=1,10                                                        5731
1     IF(CONC(3).LT.SCONC(3,K)) GO TO 11315                                  5732
2   11310 CONTINUE                                                           5733
3   11315 CONTINUE                                                           5734
      SIM(3,K,MO)=SIM(3,K,MO)+1                                              5735
4     DO 11330 K=1,10                                                        5736
5     IF(CONC(6).LT.SCONC(6,K)) GO TO 11335                                  5737
6   11330 CONTINUE                                                           5738
    11335 CONTINUE                                                           5739
7     SIM(6,K,MO)=SIM(6,K,MO)+1                                              5740
8     DO 11336 K=1,10                                                        5741
9     IF(CONC(1).LT.SCONC(1,K)) SIM(1,K,MO)=SIM(1,K,MO)+1                    5742
      IF(CONC(2).LT.SCONC(2,K)) SIM(2,K,MO)=SIM(2,K,MO)+1                    5743
10  11336 CONTINUE                                                           5744
11    CONC(1)=CONC(1)*EXP**(-1.204)                                          5745
12    CONC(2)=CONC(2)*EXP**(-1.204)                                          5746
      IF(CONC(1).LT.5.)CONC(1)=5.                                            5747
13    IF(CONC(2).LT.2.) CONC(2)=2.                                           5748
14    IF(MPRNT.EQ.0) GO TO 11340                                             5749
15    MCOUNT=MCOUNT+1                                                        5750
16    IF(MCOUNT.LT.50) GO TO 11338                                           5751
17    WRITE(16,15000)                                                        5752
18    WRITE(16,15100)                                                        5753
      MCOUNT=1                                                               5754
19  11338 CONTINUE                                                           5755
20    WRITE(16,15200) NSTOR,KYR,KMO,KDY,J,RUNOF,S2,QO2,(CONC(KL),KL=1,6)5756
21  11340 CONTINUE                                                           5757
    11350 CONTINUE                                                           5758
22    JPREV=J                                                                5759
23    PREV=KDAY(LX)                                                          5760
24    SIM(4,K14,MO)=SIM(4,K14,MO)+URE                                        5761
      SIM(5,K15,MO)=SIM(5,K15,MO)+URE                                        5762
25  C     NOW ROUTE FOR THE HOUR OF RUNOFF                                   5763
26  11355 CONTINUE                                                           5764
27    POWER=.000285                                                          5765
28    HEFF=HEFF+1                                                            5766
      OVFL=RUNOF/APP1*646317.                                                5767
29    IF(OVFL.GT.1000.) GO TO 11400                                          5768
30    EFF=.9-.0007*POWER*OVFL**2.                                            5769
      GO TO 11410                                                            5770
31  11400 EFF=0.7*EXP**(POWER*2.*(1000.-OVFL))                               5771
32  11410 CONTINUE                                                           5772
33    DO 11440 N=1,10                                                        5773
34    STEP=N*10.                                                             5774
      IF (STEP.GT.EFF) GO TO 11445                                           5775
35  11440 CONTINUE                                                           5776
36  11445 CONTINUE                                                           5777
      K17=N                                                                  5778
37    SEFF(K17)=SEFF(K17)+1                                                  5779
38  C     POLLUTANT INPUTS IN POUNDS                                         5780
      POLIN(1)=(1.-EFF)*POLLRT(1)                                            5781
39    POLIN(2)=(1.-EFF)*POLLRT(2)                                            5782
      POLIN(3)=(1.-0.5*EFF)*POLLRT(3)                                        5783
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                POLIN(4)=(1.-0.3*EFF)*POLLRT(4)                                  5784
                POLIN(5)=(1.-0.2*EFF)*POLLRT(5)                                  5785
                POLIN(6)=2.023*RUNOF                                             5786
                SOLIDS=SOLIDS+EFF*POLLRT(1)/80.                                  5787
                S202=3600.*RUNOF+S1-Q01                                          5788
                IF(S2C2.LT.0.) GO TO 11455                                       5789
1/6             DO 11450 K=1,50                                                  5790
1               IF(ROUT2(K).GT.S202) GO TO 11460                                 5791
2           11450 CONTINUE                                                       5792
3                 GO TO 11460                                                    5793
C           11455 RESERVOIR STILL NOT FULL                                       5794
4                 S2=S1+RUNOFF*3600.                                             5795
5                 Q02=0.                                                         5796
6                 Q01=0.                                                         5797
                  GO TO 11475                                                    5798
7           11460 S2=STORR(K)                                                    5799
8                 Q02=OFLOW(K)                                                   5800
                  Q01=Q02                                                        5801
9           C     POLLUTANT ACCOUNTING FOR THE RUNOFF                            5802
10          11475 CONTINUE                                                       5802
                  DO 11480 I=1,6                                                 5804
11                CONC(I)=(CONC(I)*(S1+RVOL)*28.32+POLIN(I)*453592.4)/28.32/S2   5805
12                IF(LX.EQ.200) LX=0                                             5806
13          11480 CONTINUE                                                       5807
                  IF(MPRNT.EQ.0) GO TO 11490                                     5808
14                MCOUNT=MCOUNT+1                                                5809
15                IF(MCOUNT.LT.50) GO TO 11485                                   5810
16                WRITE(16,15000)                                                5811
17                WRITE(16,15100)                                                5812
                  MCOUNT=1                                                       5813
18          11485 CONTINUE                                                       5814
19                WRITE(16,15200) NSTOR,KYR,KMO,KDY,J,RUNOF,S2,Q02,(CONC(KL),KL=1,6)5815
20          11490 CONTINUE                                                       5816
21                S1=S2                                                          5817
22                DO 11540 I=1,6                                                 5818
                  DO 11530 KD=1,10                                               5819
23                IF(SCONC(I,KD).GT.CONC(I)) GO TO 11535                         5820
24          11530 CONTINUE                                                       5821
25          11535 CONTINUE                                                       5822
                  SIM(I,KD,MO)=SIM(I,KD),MO)+1                                   5823
26                IF(I.EQ.1) K11=KD                                              5824
27                IF(I.EQ.2) K12=KD                                              5825
                  IF(I.EQ.3) K13=KD                                              5826
28                IF(I.EQ.4) K14=KD                                              5827
29                IF(I.EQ.5) K15=KD                                              5828
                  IF(I.EQ.6) K16=KD                                              5829
30          11540 CONTINUE                                                       5830
31                CONC(1)=CONC(1)*EXP**(-1.204)                                  5831
32                CONC(2)=CONC(2)*EXP**(-1.204)                                  5832
33                IF(CONC(1).LT.5.)CONC(1)=5.                                    5833
                  IF(CONC(2).LT.2.) CONC(2)=2.                                   5834
                  RETURN                                                         5835
                  END                                                            5836
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